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Technical Report

An Iterative Design and Empirical Evaluation of Conditionals for Robotito

Ewelina Bakala, Gonzalo Tejera, Juan Pablo Hourcade

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1 Introduction

Computational thinking (CT) is the process of formulating problems and solutions in a manner that allows a computer (whether human or machine) to effectively execute them [11]. This skill is considered essential for an active participation in the digital world [22], prompting its integration into educational curricula globally [22, 5].

Researchers emphasize the importance of CT learning at the early childhood stage, and empirical studies confirm that it is viable to teach CT concepts even at preschool level [16, 17, 9, 21]. Many of these studies use robots to teach CT, as they provide a concrete reference system for abstract problems.

Robotito is an educational robot developed as an open-source and open-hardware platform to introduce computational thinking to young children [27] (see Section 2 for more details about the robot). It has shown potential in stimulating CT development in preschoolers [8]. There is evidence that it is also well-suited to support groups of children learning together with one robot [1].

Robotito enables children to work on sequencing tasks that include abstraction, decomposition, route planning, and debugging. However, it consistently responds the same way to coding cards, which prevents it from addressing advanced programming concepts like conditionals. Conditionals are a critical component of many CT definitions [6, 10, 24], and validated CT tests for children aged 5 to 6 [18, 30] evaluate understanding of conditionals.

Recognizing the importance of conditionals, we decided to extend Robotito's capabilities to include this concept. We developed three prototypes for integrating conditionals into Robotito's functionality and a simulator to illustrate these ideas without needing to implement them in the physical robot. We evaluated our prototypes with experienced teachers to identify strengths and weaknesses of each prototype, and select the most appropriate for preschool context (see Section 3).

In the next step, we incorporated activities with conditionals and Robotito's simulator into Robotito curricula. The second part of this work (see Section 4) presents the results of an ER intervention with Robotito aimed to prompt the development of CT in level 5 kindergarten children. To measure the impact of the intervention, we adapted two validated CT tests and administered them before and after the activities. Additionally, the children's understanding of Robotito related concepts was assessed using a custom assignment, the Robotito Test.

2 Robotito

Robotito is an educational robot developed at Universidad de la República (Uruguay), designed to teach children CT concepts such as trajectory planning, sequencing, decomposition, and debugging.

On its underside, it has a sensor that allows to detect color cards placed on the floor. It responds to these cards by changing its movement direction according to the detected

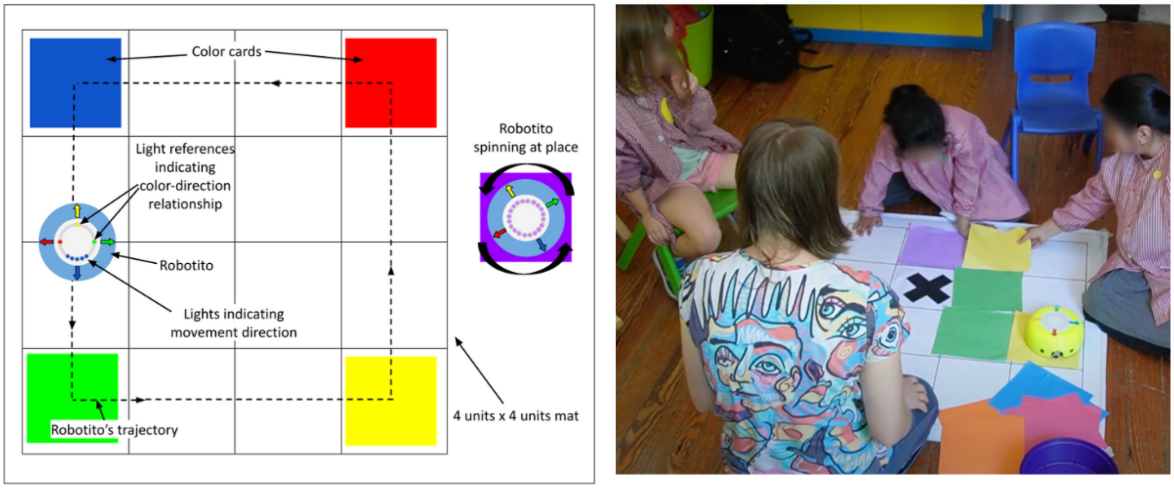

Figure 1: *Left: A schema of Robotito's response to color cards. The robot moves forward with yellow, left with red, backward with blue and right with green. Purple makes it spin. Right: An example of children solving a programming task.*

color: yellow makes it move forward[1], red to the left, blue makes it move backward, green to the right, while purple makes it spin (see Figure 1). It also responds with lights to the detected color cards. The robot indicates with four LEDs the direction it will move after sensing a particular color (see light references indicating color-direction relationship in Figure 1). When it detects a yellow, red, blue, or green card, additional LEDs light up to indicate the robot's movement direction. In the case of a purple card, all lights illuminate in purple.

During the ER actvities it is typically used with square color cards and a white mat divided into 4×4 units, 20cm×20cm each. The mat provides a homogeneous white background that enhances card detection by covering any distracting floor colors.

3 Development of conditionals

We evaluated different ideas for implementing conditionals in Robotito with three experienced teachers using prototypes with a different grade of fidelity.

3.1 Conditionals prototypes

We developed three ideas for implementing conditionals: color frame, musical mode, and split card. Each of these allows the robot to respond differently to the same coding card based on the evaluation of boolean expressions.

[1]Robotito has no front, so the relation to directions "forward", "backward", "left" and "right" are used only to distinguish its four predefined directions.

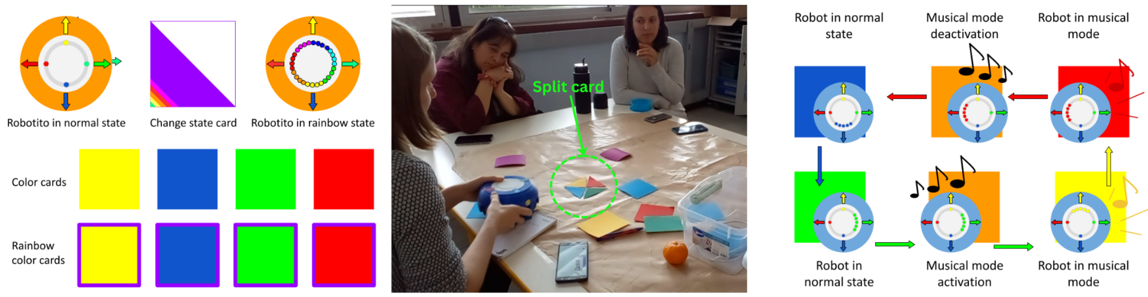

Figure 2: *On the left: An example of the implementation of color frame prototype. Depending on the state the robot responds to color cards or to rainbow color cards. In the middle: Paper prototype of the split card. When the robot approaches the card from the bottom, it senses blue and moves in the direction indicated by the blue arrow. When it approaches from the right, it senses green and moves in the direction indicated by the green arrow. Approaching from the left, it senses yellow, and from the top, it senses red. On the right: An example of musical mode activation and deactivation. The robot moves according to the color cards and produces activation/deactivation sound when passing over orange card and plays note associated with the color when passing over yellow and red card.*

3.1.1 Color frame

This prototype enables Robotito to respond differently to color cards based on the it's current state. In addition to the standard color cards, we introduce color cards with frames and a card that changes the robot's state (see Figure 2). In its normal state, Robotito detects color cards and ignores rainbow color cards[2]. In the rainbow state, Robotito does the opposite: it detects rainbow color cards and ignores color cards. The change state card is used to switch between states. Consequently, the robot behaves differently when encountering the same event (color card detection), depending on its state. The conditional logic expressed by this prototype is:

if $mode == rainbow$ **then**
    if $card == rainbowCard$ **then**
        $move(cardColor)$
    end if
else
    if $card == colorCard$ **then**
        $move(cardColor)$
    end if
end if

[2] The rainbow state is an example of a state the robot could implement. In our evaluations, we discussed other state changes, such as becoming angry or happy, to illustrate with a concrete example the new functionality.

3.1.2 Split card

The split card is a multicolor card containing four sections (see Figure 2). Each section can have a different color, although it is also possible to have sections with repeated colors. The direction in which the robot will move after detecting the card depends on the side from which the robot approaches it. This allows a single card to encode up to four different directions for the robot. The card can be rotated to solve a programming task. The conditional logic expressed by this card is:

if $comingFrom == bottom$ **then**
  $move(bottomCardColor)$
else if $comingFrom == right$ **then**
  $move(rightCardColor)$
else if $comingFrom == left$ **then**
  $move(leftCardColor)$
else
  $move(topCardColor)$
end if

3.1.3 Musical mode

This prototype incorporates two states for the robot: the normal state and the musical state. In the musical state, the robot executes its usual direction changes in response to color cards but also produces different sounds for each color card (see Figure 2). The state change occurs when the robot passes over the change state card (orange card) and is indicated by an activation or deactivation sound. This functionality allows the robot to perform an additional action—sound reproduction—when it is in musical mode. The conditional expressed by this prototype is:

if $mode == musical$ **then**
  $playSound(cardColor)$
end if

3.1.4 Robotito simulator

To evaluate our ideas without the need for immediate implementation in the physical robot, we developed Robotito simulator. It is a digital version of the robot that can be deployed as a desktop or Android application. It reflects the behavior of the robot and has been extended to incorporate additional features that we wanted to evaluate. The simulator was developed using the Processing [3], a programming language build on top of Java that facilitates rapid prototyping of interactive systems. The code of the musical mode and split card simulators can be found in the following repositories: https://github.com/ewelinka/robotitoMusical, https://github.com/ewelinka/robotitoSplitCard.

[3] https://processing.org/

Id	Date	Participants	Prototype evaluated	Evaluation type
1	07.06.23	P1, P2	Color frame Musical mode Split card	Focus group with both teachers based on oral explanation, paper prototype of new cards, and a researcher simulating Robotito's actions "by hand".
2	02.08.23	P1, P2	Musical mode Split card	Individual interview with each teacher using on screen Robotito simulator.
3	15.08.23	P3	Musical mode	Oral explanation of the new functionality and an interactive instance with the first implementation of musical mode in Robotito.
4	19.08.23	P3	Musical mode	Asynchronous feedback on a video generated using Robotito's simulator.

Table 1: *Summary of the evaluation sessions.*

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During evaluations, we utilized the simulator as a desktop application and also used it to generate videos, which were later shared with teachers. Examples of simulations of the musical mode and split card can be found on YouTube[4].

3.2 Methodology

We conducted four evaluation activities involving three teachers. Each activity was video recorded and analyzed.

3.2.1 Participants

The participants included: a computing teacher who works with preschoolers and early primary school students at a private educational center (P1); a teacher who teaches at both public and private institutions at the preschool and primary school levels (P2); and a preschool teacher from a public institution (P3). P1 and P2 participated in the first two evaluation sessions, while P3 participated in the third and fourth evaluation. All participants work in schools in Montevideo, Uruguay and had more than 15 years of teaching experience.

3.2.2 Evaluation activities

Before evaluating the prototypes, all teachers were familiarized with Robotito and its responses to color cards. During the evaluations, we presented our ideas using various strategies: oral explanations, paper prototypes of new color cards, simulating Robotito's actions "by hand" with the robot turned off, utilizing the Robotito simulator, and using Robotito itself. As we made improvements between the evaluations, each session employed different evaluation materials. Details of each session are provided in Table 1.

[4] https://www.youtube.com/playlist?list=PL575oRsFVM9qjtbGgaP6RRVXiNXM176Wu

3.3 Results

Each evaluation provided valuable input, helping us identify the most appreciated ideas and focus on potential improvements for subsequent evaluations.

3.3.1 Evaluation #1 (low fidelity prototypes)

We conducted a focus group with P1 and P2 to discuss all the ideas. The session involved a verbal explanation of each prototype, paper prototypes of new cards, and a researcher simulating Robotito's actions "by hand".

Color frame The idea of additional cards and an internal state that completely alters the robot's reaction to color cards was considered complex. P2 remarked that "everything changes" and that "there are two parallel universes."

To provide a concrete example that would justify the use of color frames, P2 suggested an activity based on missions. In this scenario, the robot might fall or crash if it follows a path composed of only one type of card (either directional cards or directional rainbow cards, depending on the state). The challenge would be to change the robot's state at the appropriate moment to avoid these unwanted situations and achieve the goal, although P2 admitted, "Still, it is difficult." P1 envisioned that borders could have textures influencing the robot's behavior, such as a green border with a grass texture that slows the robot down. She suggested that patterns on the borders could be more concrete and have an immediate effect that is easily understood at the preschool level.

Split card P1 questioned the benefits and new challenges introduced by the split card: "In the end, it does the same as if you put this (blue card) here. Why do you divide it into four? What makes it different?" P2 suggested that "Perhaps you can give the card with four colors to the child and the child has to decide how to rotate it." They noted that the robot's starting position and orientation should be predefined so the child can solve the task. P2 observed, "I have to consider where it starts, what will be the first color that it senses, and which direction it will go." Additionally, they mentioned the need to account for the number of coding cards or obstacles to ensure the children would use the split card. Both teachers admitted that using the split card was not straightforward. P2 stated, "You have to think well about the tasks," and P1 added, "You have to consider the context." P2 summarized these considerations by stating, "The use of the (split) card is somehow forced."

Despite these concerns, P2 remarked that she really liked this idea and P1 found it attractive.

Musical mode After the researcher's explanation, the teachers immediately focused on the idea of creating melodies using color cards. We discussed potential issues, such as when the robot should repeat two notes, causing it to loop between two cards, and then play a new note. In this scenario, the card with the new note should be placed while the robot is moving to interrupt the loop. P1 suggested that when the robot is in musical mode, it could maintain a fixed movement direction and only read the notes: "Do not modify the direction variable, leave it fixed." She was enthusiastic about working on sequencing using popular melodies or songs, such as "Baby Shark." She stated, "The song guides the order," and "the ear corrects you."

Summary All the prototypes presented challenges that were noted by the teachers. They proposed various ideas to overcome these challenges and considered classroom activities that could employ each prototype.

The color frame prototype was the only one that did not receive positive feedback, and the potential activities with it were considered difficult. Therefore, we focused further evaluations on the split card and musical mode.

3.3.2 Evaluation #2 (simulator)

During the second evaluation, we used the simulator to provide an interactive experience with the musical mode and split card prototypes. We worked with P1 and P2 separately.

Musical mode In the digital version of the musical mode, the card used to activate and deactivate musical mode would make a sound corresponding to on or off, with musical mode adding a musical note to the change of direction. This implementation of the musical mode was easily understood by both teachers. P1 remarked, "Ah! It [the color card] converts into notes. In addition to direction, it is a note." She also commented on the clarity of the activation and deactivation sound: "It is understandable that the sound is turning on and off. It's very clear." She was confident that children would understand the musical mode: "The only thing that changes is that it incorporates sound. It is not a substantial change. [...] It doesn't confuse, doesn't dazzle, this is what I'm saying."

Both teachers agreed that activating and deactivating the musical mode with the same card was a good idea. P1 noted, "with the same [card] it's easier, thinking in practice."

P1 envisioned composing simple melodies as a sequencing exercise. Although only four notes can be used with four colors, she did not see this as a problem: "At the initial level we do simple things," and "more sequence is more abstraction and more difficulty." She saw composing as engaging and emphasized that "when they [the children] are motivated they will want to spend more time working with the code."

P2 also showed interest in programming simple songs but saw working with only four sounds as a limitation. She revisited the idea from the first evaluation session, where the robot in musical mode does not change its direction but only reads the color cards as notes. This way, the robot would move as usual with color cards or go in a straight line while reproducing the sounds associated with the color cards. She considered combining these two modes challenging: "We are dividing [children's] attention between two different things, and we are working with young children." However, she saw it as viable for level 5 kindergarten (children aged 5 to 6) after some initial work with the concepts. The basic version of the prototype, in which the robot moves with the colors and in musical mode also reproduces the sound, was considered easy to understand: "The only thing that you add is that it makes sound, the movements do not change" (P2). An exercise where the children have to activate and deactivate the sound to create silence or sound in specific parts of the route was considered viable: "It's a good proposal," stated P2.

Split card The split card prototype was less discussed. P1 considered it accessible for the children since they only need to apply the color-direction rule that they already know. She imagined an introductory exercise where the normal color card is replaced by the split card to demonstrate that "it is the same."

P2 was more enthusiastic, stating, "It's incredible, I love it." She found it suitable for preschoolers and highlighted that it allows working on problems using a trial-and-error strategy.

Prototypes' ranking We asked the teachers to rank the prototypes based on their suitability for preschool-level education.

P1 found both ideas attractive for preschoolers. Regarding which prototype would allow her to offer more engaging activities, her preference was musical mode. While she found the split card idea attractive, she noted its limitation, stating, "It is not more than changing the direction."

P2 shared the same preferences, stating, "I would start with the musical one; I really like the musical one. Then the split card; I really like that one too."

Robotito simulator Both teachers spontaneously mentioned that the Robotito simulator could be used to introduce Robotito to children before working with the real robot. P1 commented on the benefit of having both virtual and tangible formats: "If I have to work on it [an activity with Robotito], I would like to explain a little bit of theory, [...] let them see it first [on the screen], and then we do it [with the robot]. This way, their anxiety decreases since they have already seen it and know how it works, and the child is more self-regulated." P2 found that "it [the simulator] is excellent to work beforehand" and "[in the simulator] we observe what it does and then, we translate it into [robot's] trajectory."

When asked if the digital version was understandable or perhaps too abstract, both agreed that the representation of the robot and the mat were appropriate. P1 remarked, "No, it is perfect, less is more."

Summary Both teachers ranked musical mode as their preferred prototype for young children due to its potential for developing playful activities involving sound and movement. It was deemed more engaging compared to solely focusing on directional changes, as seen with the split card.

Interestingly, both teachers highlighted the benefits of using the Robotito simulator to introduce Robotito to children before using the physical robot. They appreciated the combined use of virtual and tangible formats to provide better learning experience.

3.3.3 Evaluation #3 (high fidelity prototype)

During the third evaluation, the researcher that led the session presented to P3 the in-robot implementation of musical mode. The educator spontaneously began interacting with the robot, attempting to make it play the first part of Beethoven's composition "Für Elise." The challenge of composing a melody with four notes while the robot changes direction with each color was considered complicated. "It is too much," stated P3. She acknowledged that "they [the children] will love it" and that it "sparks creativity," but felt it was too complex for kindergarten.

The researcher mentioned that in previous evaluations, the idea of fixing the movement direction in musical mode had been proposed so that children could focus on the notes without needing to think about direction changes. However, this idea did not convince P3. She found using the same cards for both directions and music confusing. She explained that the idea could work "if these cards had a drawing of a musical note or something to differentiate them from the others, otherwise, it's a mess."

P3 considered the concept of passing in silence or making sound in some parts of the robot's route much more viable: "[The option] to go with sound or without sound is great." She was undecided on whether there should be two separate cards to activate and deactivate the musical mode, or if one card would suffice.

Summary During the third evaluation, the teacher found the musical mode engaging but too complex if the objective is composing melodies while managing direction changes. The idea of fixing the robot's direction in musical mode to focus on notes was not convincing. The concept of the robot passing in silence or making sound at specific points was seen as more viable. There was uncertainty about whether one or two cards should be used to activate and deactivate the musical mode.

3.3.4 Evaluation #4 (simulator's video)

The video of the musical mode simulator[5] presented to P3 was deemed "super clear." She found that it accurately reflects Robotito's behavior that she experienced in the previous evaluation session: "I think I was watching exactly how the robot works." However, she noted the absence of visual feedback to indicate whether Robotito is in musical mode: "What caught my attention [...] is that there's nothing visually indicating that it's in musical mode. I didn't see any different light turning on; you can only tell if you hear the sound or not."

[5] https://www.youtube.com/watch?v=Ju89amk-yTs

3.4 Discussion

3.4.1 Prototypes

All the prototypes we evaluated presented certain challenges, and exchanges with the teachers helped us focus on the most viable ideas and incorporate improvements.

The color frame prototype was considered too demanding, as it relied on an if-then-else condition that would require children to manage “two parallel universes,” each with a different set of coding cards. In contrast, the other prototypes were simpler, requiring only one additional coding card. Both were found attractive, but the decisive factor in the teachers’ preferences was the potential to explore new actions in musical mode. Sound reproduction was considered engaging, and activities involving passing through certain parts of the robot’s route in silence or with sound were seen as accessible for preschoolers. While the teachers were enthusiastic about composing melodies, they were also aware of the difficulties associated with combining sound and direction or separating the musical mode from the directional mode. The viability of music composition should be validated in future studies.

The interaction with the teachers helped validate specific aspects of the musical mode implementation. For example, the teachers suggested using a single card to activate and deactivate the mode. They also provided examples of activities and identified potential improvements, such as adding visual cues to indicate whether the robot is in musical mode.

3.4.2 Robotito simulator

The teachers saw the simulator as a valuable tool for introducing Robotito to children. They noted that presenting the robot on a screen or projecting it onto a whiteboard would be less distracting for the children since it cannot be touched or grabbed. They envisioned using it to explain the color-direction relationship or introduce a specific activity before interacting with the real robot, thereby reducing the children’s anxiety.

The enthusiastic reaction of the teachers helped researchers envision the simulator’s use as a tool not only for introducing the robot but also for practicing programming individually. The same code used to generate the desktop simulation can be deployed as an Android application, allowing interaction with digital coding cards and an on-screen Robotito by dragging them with a finger. Given that each public preschool in Uruguay is equipped with Android tablets, we began considering incorporating programming Robotito on the tablet as part of Robotito’s curriculum.

Although the simulator can help in practicing robot programming individually, it is essential to combine its use with hands-on experiences with the actual robot. While the simulated Robotito scenario is useful for practicing trajectory programming, it lacks the ability to incorporate new elements, making it challenging to engage children through activities like personalizing the robot or adding characters and decorations to build a narrative. The limited flexibility of the simulated scenario also hampers integration with preschool curricula. We consider that simulators can reinforce the learning experience, but they should be complemented by tangible robots that offer concrete materials and greater flexibility for incorporating new elements.

4 Field study

Drawing from the insights gained during prototypes evaluation, we enhanced Robotito's capabilities by adding a musical mode. We then incorporated activities involving both Robotito's simulator and the new musical mode into the curriculum implemented during the field study.

The following research questions guided the field study:

- What was the impact of activities with Robotito on children's computational thinking development?
- Can preschool children understand and successfully use conditionals?
- Is there a correlation between the validated PC tests and between the tests and Robotito Test?

4.1 Methodology

We conducted a study with a quasi-experimental design to evaluate whether a curriculum of eight educational robotics (ER) sessions with Robotito influenced the development of computational thinking in the active group, compared to the control group. The study involved an active group (AG) composed of two classes (A1, A2) and a control group (CG) consisting of one class. The activities focused on trajectories planning, sequencing, and conditionals. We adapted two validated CT tests for preschoolers to measure CT levels before and after the activities. We also developed a custom assignment, the Robotito Test, to evaluate children's understanding of the concepts introduced in the ER sessions. This test was administered after ER sessions and only to the AG.

4.1.1 Robotito

As discussed in Section 2, Robotito moves in response to five color cards: yellow, green, blue, red and purple. In this study, two additional color cards were introduced: orange, for conditional music reproduction, and pink, to familirize children with the concept of modularization. After detecting the pink card, Robotito moves one step forward (yellow direction), then one step right (green direction), and stops the movements. During the execution of this "pink step," the robot ignores all other color cards.

4.1.2 Participants

We worked with 56 preschoolers from level 5 (5 to 6 years old) at a public kindergarten in Montevideo, Uruguay. Two classes (A1 with 17 students and A2 with 19 students) formed the AG, and one class (20 students) was the CG. A1 attended the kindergarten in the morning, and A2 and CG were the afternoon groups. The assignment to the AG and CG was decided by the kindergarten's principal.

4.1.3 Activities

We conducted eight ER activities with Robotito between November and December of 2023 (see Table 2). The activities were designed taking into account lessons learned from two exploratory studies [3], new capabilities of the robot, and ideas from a preschool teacher who worked with Robotito in her classroom. A detailed description of all activities can be found in Appendix E.

4.1.4 Data collection and analysis

We assessed children's CT levels at two time points: before starting the activities with Robotito and at the end of all sessions. We also examined children's knowledge related to the concepts addressed in the activities with Robotito using the Robotito Test that we developed. All the tests were administered individually to the children, and three evaluators participated in the evaluation process. We performed statistical analysis and data visualization using the R programming language [6].

Additionally, we video recorded all the activities and the Robotito Test administration to enrich our analysis with qualitative data.

Evaluation Instruments We adapted two CT tests [18, 30] to measure CT before and after the activities. We chose them because they are the only existing validated tools for our age group. Additionally, we developed a custom test, the Robotito Test, to evaluate children's understanding of the concepts introduced during the ER activities.

The Beginners Computational Thinking Test (BCTt) [30] targets children aged 5 to 12 and consists of 25 items assessing Sequences (6), Simple Loops (5), Nested Loops (7), If-then Conditional (2), If-then-else Conditional (2), and While Conditional (3). We tailored the test by retaining items relevant to our study and reducing the number of questions related to Loops, as they were not explicitly addressed in our curriculum. Our adapted version comprises 13 items, covering Sequences (items 1 to 6), If-then Conditional (items 7 and 8), Simple Loops (item 9), and Nested Loops (items 10 to 13). These items correspond to items 1, 2, 3, 4, 5, 6 (Sequences), 19, 20 (If-then Conditional), 8 (Simple Loops), 13, 14, 15, 17 (Nested Loops) in the original BCTt. The tailored test used in the study can be found in Appendix A.

[6] https://www.r-project.org/

Activity	Date, class (nr of children)	Modality of work	Main goal of the session
#1	06.11.23 A1 (14) 06.11.23 A2 (18)	Whole class together.	To introduce Robotito and how it moves with yellow, red, green and blue color cards.
#2	10.11.23 A1 (16) 10.11.23 A2 (18)	The class splitted in two groups.	To reinforce how the robot responds to color cards through an embodied experience. To observe that the color cards should be placed in the robot's trajectory.
#3	20.11.23 A1 (16) 17.11.23 A2 (18)	The class splitted in two groups.	To understand that directing the robot depends on the color of the coding card and the robot's rotation. To reinforce that the color cards should be placed in the robot's trajectory.
#4	22.11.23 A1 (16) 20.11.23 A2 (19)	Whole class together.	To reinforce how the robot responds to color cards through more individual interaction with Robotito's simulator. To practice route planning, sequencing and sequence decomposition.
#5	24.11.23 A1 (15) 24.11.23 A2 (15)	The class splitted in two groups.	To plan Robotito's trajectories, select the corresponding color cards, and place it in space. To introduce conditional music reproduction using the orange card.
#6	27.11.23 A1 (14) 24.11.23 A2 (16)	The class splitted into small groups.	To practice coding Robotito's routes and reinforce how it responds to the orange card.
#7	29.11.23 A1 (14) 29.11.23 A2 (17)	The class splitted in two groups.	To introduce a pink card that makes the robot execute a prerecorded sequence of movements and stop.
#8	04.12.23 A1 (14) 04.12.23 A2 (18)	The class splitted into small groups.	To reinforce how the robot responds to the pink card and practice combining it with the other coding cards.

Table 2: *Summary of ER sessions.*

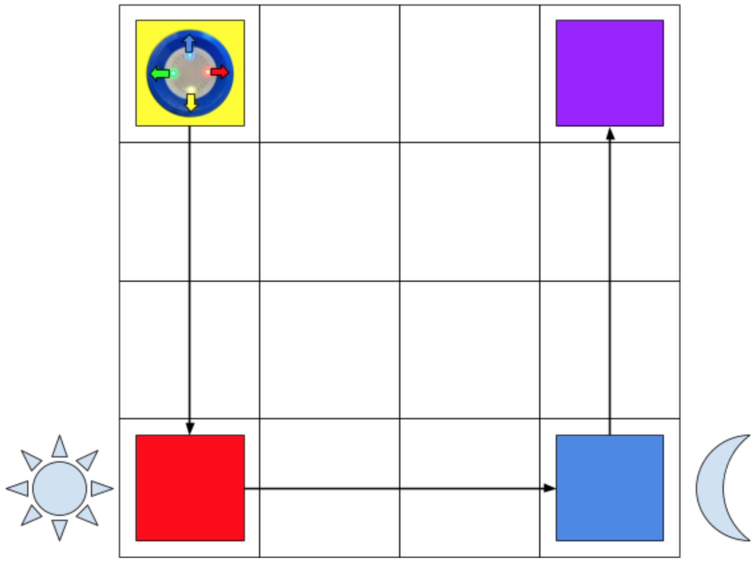

Figure 3: *Task 3 from Robotito Test. Children have to place orange cards so that Robotito makes sounds near the sun and is silent near the moon.*

TechCheck-K [18] is a kindergarten version of TechCheck (a validated CT test that targets children aged 6 to 9 [19]). It targets children aged 5 to 6, and evaluates 15 items related to Hardware/software (2 items), Debugging (2), Algorithms (5), Modularity (2), Representation (2), and Control Structures (2). We used a tailored version of the test that contained only items relevant in our study, resulting in 9 items focusing on Algorithms (items 1 to 5), Representation (items 6 and 7), and Control Structures (items 8 and 9). These items correspond to items 5, 8, 9, 10, 11 (Algorithms), 12, 13 (Representation), 14, 15 (Control Structures) in the original TechCheck-K. The tailored test used in the study can be found in Appendix B.

Robotito Test was developed to assess children's understanding of the concepts that we addressed in the ER activities. All the tasks represent on paper a typical activity setting (Robotito, a 4×4 units grid, and color cards). See Appendix D to visualize the test.

In the first task, children have to choose the colors of two coding cards to guide the robot to the purple card. The route and cards' locations are predetermined, requiring only the selection of cards' colors. This task assesses whether children understood the color-direction relationship and can deduce it from a particular robot's orientation to solve a specific sequencing task.

The second task entails designing a sequence of movements for the robot to reach the purple card while defining both the location and color of the coding cards.

In the third task, children's comprehension of conditional music reproduction is evaluated. Here, the U-shaped sequence of the robot's movements is predetermined, with corresponding cards already in place (see Figure 3). Children are tasked with positioning orange cards to activate or deactivate Robotito's sounds at two specific points along its route.

The fourth task evaluates the correct usage of the pink card. With the robot initiating its movements on the pink card and aiming to reach the purple card, children are asked to place the missing cards to complete the programming sequence.

We provided the children with four color cards (yellow, red, green, blue) to solve the task 2 and 4, and with two orange cards to solve the task 3. Each task was evaluated as correctly solved (1 point) or incorrectly solved (0 points) without decimal scores. Administration was conducted by a single researcher, who could scaffold children with questions like:

- "Can you show me with your finger how the robot will move?" (Task 2 and 4)
- "How does the robot move with the pink card?" (Task 4)

and explain issues that were different between the on-paper robotic task and the real robot acting:

- "It is ok to cover the robot with a color card, it's the same as placing it below the robot." (Task 2)
- "You can not cover printed color cards with the orange card." (Task 3)

These measures aimed to enhance qualitative analysis by providing insight into children's reasoning and comprehension, and ensure that the children understood the on-paper programming setting.

Statistical analysis We conducted statistical analysis to identify differences between PRE and POST scores across the AG (comprising A1 and A2) and CG in CT tests (tailored TechCheck-K and BCTt), correlations between CT tests, and correlations between Robotito Test and CT tests. We used the Shapiro-Wilk test [23] to assess the normal distribution of the samples and Bartlett's test [4] to examine the variance between groups. Group comparisons were performed using the two-sample t-test [7], the Wilcoxon rank-sum test [29], and factorial ANOVA [28]. Comparisons between PRE and POST results within the same group were made using the paired t-test [13] and the Wilcoxon signed-rank test for paired data [29]. Wilcoxon tests were used when the data did not follow a normal distribution. The correlation between the tests' scores was calculated using the Pearson correlation coefficient (PCC) [12] for data that follows a normal distribution, and the Spearman rank correlation coefficient (rho) [25] otherwise.

4.2 Results

We analyzed whether there was a difference between the AG (composed of A1 and A2 classes) and CG in overall scores (PRE and POST scores together) and in PRE and POST scores separately. We were also interested in determining whether there was

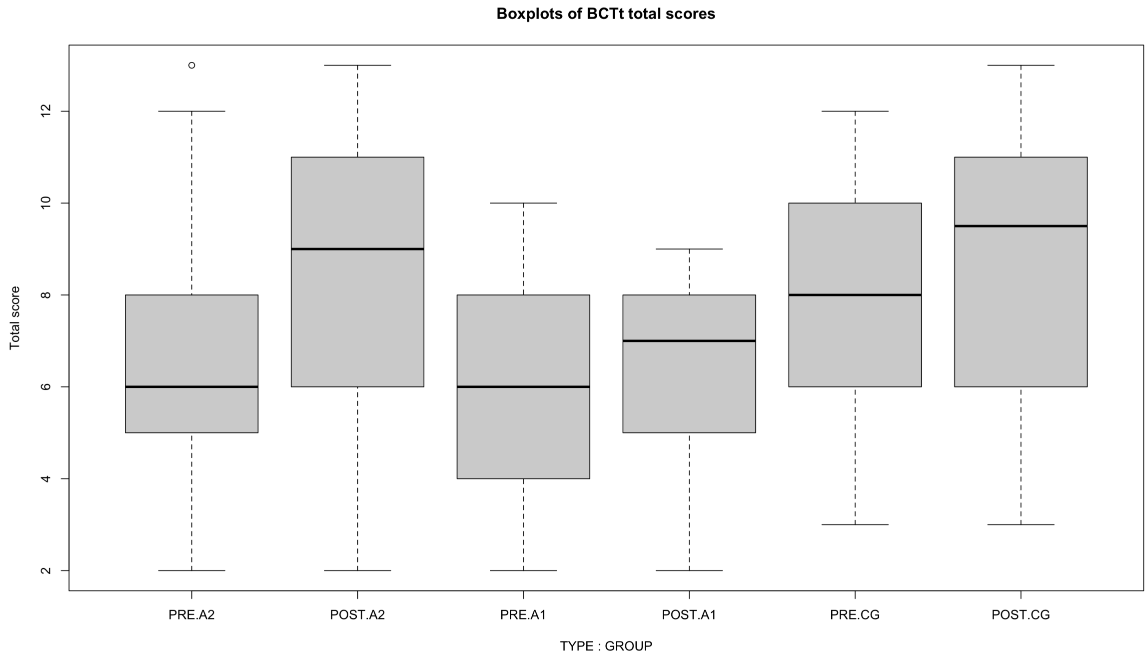

Figure 4: *Boxplots of PRE and POST total scores of each class.*

an improvement in any specific CT concept (Sequencing, If-then Conditional, Simple Loops, and Nested Loops in case of BCTt; Algorithms, Representation, and Control Structures in case of TechCheck-K) and if our results were similar to those reported in the literature. Finally, we analyzed if the tests' results show any correlation.

The tests' results can be consulted in Appendix G (BCTt), Appendix H (TechCheck-K), and Appendix I (Robotito Test) or downloaded from `https://drive.google.com/drive/folders/1FrFkTNljsb23nL3QeeY-3FdFHHOhwJ_v?usp=sharing`.

4.2.1 BCTt

PRE and POST scores in AG and CG All the samples that we compared had a normal distribution, so we performed two-sample and paired t-tests, and factorial ANOVA analyses.

Was there a significant difference in PRE or POST scores between AG and CG?

The two-sample t-test revealed a significant difference (p=0.018) between the BCTt scores of the AG (mean=6.889) and the CG (mean=8.2). Although the AG had a lower mean PRE score than the CG (see Table 3), this difference was not statistically significant (p=0.058). Both groups improved their performance in the POST test; however, the mean POST score of the AG (mean=7.417) did not manage to reach the mean PRE score of the CG (mean=7.75). There was no statistically significant difference between the POST scores.

We further analyzed PRE and POST scores by dividing the AG into classes (see

	PRE	POST
CG	7.75	8.65
AG	6.361	7.417
A1	6.0	6.053
A2	6.684	8.211

Table 3: *BCTt mean PRE and POST score of the AG, A1, A2 and CG.*

Table 3 and Figure 4) to identify any differences in performance between the active groups (A1 and A2) and between the active groups and the CG.

We found a significant difference in PRE test scores between A1 and CG (p=0.043), but not between A2 and CG, nor between A1 and A2. Similar results were observed when comparing POST scores: there was a significant difference only between A1 and CG (p=0.015).

Have the groups improved their scores?

We conducted paired t-tests separately for each group to assess whether there was a significant improvement within each group.

The paired t-test demonstrated that the AG significantly improved its BCTt score (p=0.034, mean difference=0.9), while the CG showed no significant improvement. Class-by-class analysis revealed that only A2 significantly improved its BCTt score (p=0.042, mean difference=1.526), whereas A1 showed no statistically significant improvement.

Does the change in scores over time depend on the group variable?

Factorial ANOVA confirmed a significant difference (p=0.019) between the AG and the CG overall scores (PRE and POST scores together), indicating that, in general, the CG performed better than the AG. At the interaction level, which considers both time and group, the only significant difference found was between CG:POST and AG:PRE (p-value=0.020).

The analysis of the three classes (A1, A2, CG) showed a significant difference (p=0.009) in scores only between A1 and CG groups. The interaction between PRE and POST conditions and the three groups indicated a significant difference only when comparing A1:PRE and CG:POST. The significant difference between A2:PRE and A2:POST scores identified using the t-test was not confirmed by the ANOVA analysis.

PRE and POST concept scores in AG and CG We grouped the scores of questions related to Sequencing, If-then Conditional, Simple Loops, and Nested Loops (see Section 4.1.4 for questions related to each concept) and compared the scores.

Which concepts related to CT improved over time?

To determine which concept scores improved over time, we compared PRE and POST scores of each group (AG, CG, A1, A2). In only four cases (A2 Sequencing, A1 If-then Conditional, CG and A2 Nested Loops) did the difference between PRE

Id in adapted BCTt used in our study	BCTt item id	Percentage of correct answers for the first educational stage in [30]	Percentage of correct answers in our study
1	1	93%	62%
2	2	93%	64%
3	3	91%	73%
4	4	89%	61%
5	5	76%	52%
6	6	87%	57%
7	19	71%	50%
8	20	41%	29%
9	8	77%	50%
10	13	76%	64%
11	14	55%	27%
12	15	27%	25%
13	17	96%	71%

Table 4: *Percentage of correct answers for items evaluated in our study. Comparison of Table 17 values from [30] and our score calculated as a mean PRE value of all groups (A1, A2, CG).*

and POST scores show a normal distribution. For these cases, we performed a paired t-test; for the others, we used a Wilcoxon signed-rank test for paired data.

Sequences and Nested Loops scores showed no significant difference when comparing PRE and POST scores of any group. The If-then Conditional score improved only in the CG (p-value=0.044), and Simple Loop score in the AG (p-value=0.022).

Comparison with other studies To determine if our results align with those reported in the literature, we analyzed studies that report BCTt scores. We found only two relevant studies providing a percentage of correct answers for our age group. The study by Zapata-Cáceres et al. [30] presents the percentage of correct answers by concept (see the first column in Table 5) and by individual question (see the third column in Table 4) for children aged 5 to 8. The second study by Zapata-Cáceres and Fanchamps [31] presents the percentage of correct answers grouped by concept specifically for 5-year-olds (see the second column in Table 5).

Percentage of correct answers of each item

Correlation analysis of the percentage of correct answers for each item revealed strong (rho=0.930) correlation between Zapata-Cáceres et al. [30] results and the PRE test results for all samples (AG and CG combined). Although the scores of [30] are consistently higher than ours (see Table 4), this discrepancy is expected, as they report scores for the first educational stage that includes children between 5 and 8, while our study was conducted with younger children aged 5 to 6.

Percentage of correct answers grouped by concept

When analyzing percentage of correct answers grouped by concept (see Table 5),

	Zapata et al. [30]	Zapata-Cáceres and Fanchamps [31]	Our study
Sequences	90%	59%	62%
If-then Conditional	44%	30%	39%

Table 5: *Percentage of correct answers for Sequences and If-then Conditional. Scores reported in Figure 15 in [30], Table 3 in [31], and our score calculated as a mean PRE value of all groups (A1, A2, CG).*

we found that our PRE scores for the entire sample (AG and CG combined) were similar to the results reported by Zapata-Cáceres et al. [30] and Zapata-Cáceres and Fanchamps [31], except for the Sequences scores from [30], which were significantly higher than our results.

Summary of BCTt results Our analysis showed that in general, CG performed significantly better than AG. However, when comparing only PRE or POST scores individually, no statistically significant difference was observed between the two groups. Between classes comparisons showed a significant difference between A1 and CG.

Comparison of PRE and POST scores of the groups showed that AG significantly improved its scores, and class-by-class analysis showed improvement only in the case of A2. When analyzing CT concepts, we observed only two improvements- the If-then Conditional score in CG and the Simple Loop score in AG.

The ANOVA interaction between time and group variables demonstrated a significant difference only when comparing A1:PRE and CG:POST, which indicates that the changes in scores over time (PRE, POST) do not depend on the group variable (AG, CG, or A1, A2, CG).

The BCTt percentage of correct answers for each item showed strong correlation between our PRE test results and those reported in [30]. When grouped by concept, our PRE results were similar to those in [30] and [31], except for the Sequences score reported in [30], which was higher than our result.

4.2.2 TechCheck-K

We analyzed if there was a difference between the AG and the CG in overall scores (PRE and POST combined) and between PRE and POST scores of each group (AG, CG, A1, A2). We were also interested if there was an improvement in any specific concept related to CT (Algorithms, Representation, and Control Structures).

PRE and POST scores in AG and CG We analyzed the distribution of the overall scores of the AG and the CG, and PRE and POST scores of all groups (AG, CG, A1, A2). Only overall AG scores and AG:PRE scores did not follow a normal distribution.

	PRE	POST
CG	4.65	5.0
AG	4.639	5.278
A1	4.418	5.176
A2	4.842	5.368

Table 6: *TechCheck-K mean PRE and POST score of the AG, A1, A2, and CG.*

Was there a significant difference in PRE or POST test between AG and CG?

To compare the scores, we used a two-sample t-test or, if the data had a non-normal distribution, we used the Wilcoxon rank-sum test. We observed that general TechCheck-K scores and PRE and POST scores were similar in AG and CG (see Table 6), and a statistical analysis confirmed that there was no significant difference between the scores.

We compared PRE and POST scores between active classes (see Table 6), and PRE and POST scores of each class compared to CG, but these more detailed analyses did not reveal any significant differences either.

Have the groups improved their scores?

We compared PRE and POST values of all groups to see if there were significant changes. In the case of A1, the difference between POST and PRE scores did not have a normal distribution, so we used the Wilcoxon signed-rank test for paired data to compare the data, in all other cases, we used the paired t-test. None of the comparisons showed a significant difference between the scores.

PRE and POST concept scores in AG and CG We grouped the scores of questions related to Algorithms, Representation, and Control Structures (see Section 4.1.4 for questions related to each concept) and compared the scores.

Which concepts related to CT improved over time?

To define which concepts improved over time, we compared PRE and POST scores of each group (AG, CG, A1, A2). We used the paired t-test, and in the cases of score difference with non-normal distribution (A2 Algorithms, AG and A2 Representation, and all groups in Control Structures), we used the Wilcoxon signed-rank test for paired data. Only the AG Control Structures significantly improved over time.

Comparison with other studies We identified three publications that report scores of individual items [18] or CT concepts [20, 14] at kindergarten level. The studies involved 89 kindergarten students in [18], 395 in [20], and 24 in [14].

Percentage of correct answers of each item

Relkin and Bers [18] report the percentage of correct answers of each TechCheck-K item (see the third column in Table 7). We observed a strong correlation (rho=0.782) between the percentages of correct answers of the entire group (AG and CG combined)

Id in adapted TechCheck-K used in our study	TechCheck-K item id	Percentage of correct answers for kindergarten estimated from [18]	Percentage of correct answers in our study
1	5	58%	48%
2	8	59%	68%
3	9	60%	57%
4	10	55%	39%
5	11	33%	27%
6	12	33%	27%
7	13	31%	41%
8	14	67%	84%
9	15	56%	73%

Table 7: *Percentage of correct answers for items evaluated in our study. Comparison of values estimated from Figure 4 from [18] and our scores calculated as a mean PRE value of all groups (A1, A2, CG).*

in the PRE evaluation and those reported in their study (see Table 7).

Percentage of correct answers grouped by concept

Relkin et al.'s [20] study provides a percentage of correct answers for each CT concept (see the first column in Table 8). Our results are similar, with our scores being slightly higher for Algorithms and Representation and considerably higher for Control Structures. Lin et al.'s results [14] (see the second column in Table 8) were slightly higher than our results.

Summary of TechCheck-K results We compared the overall, PRE, and POST scores of AG and CG and found no significant differences. There was also no difference when we compared the scores across classes.

None of the groups significantly improved its general, PRE, or POST score. Only AG improved the score of Control Structures over time.

As the comparisons of the PRE and POST scores showed no differences, we did not conduct ANOVA to analyze if the change in scores over time depends on the group variable, as we did when analyzing BCTt scores.

We observed a strong correlation between the percentage of correct answers of each item for our entire sample and those reported in Relkin and Bers [18]. When analyzing percentage of correct answers by concept, our results were similar to those in Relkin et al. [20], although our score for Control Structures was considerably higher. The scores reported by Lin et al. [14] were slightly higher than our results.

4.2.3 Robotito Test

We conducted a quantitative analysis of the scores and a qualitative analysis of the videos from the test administration process.

	Relkin et al. [20]	Lin et al. [14]	Our study
Algorithms	42%	53%	48%
Representation	32%	34%	34%
Control Structures	58%	84%	79%

Table 8: *Percentage of correct answers for three CT concepts. Scores from Relkin et al.[20] were estimated from Figure 3. Scores from Lin et al. [14] were reported directly in Table 6; for comparison, we averaged the PRE scores of the plugged and unplugged group and converted them into percentages by dividing them by the maximum possible score for each concept (5 for Algorithms and 2 for Representation and Control Structures). Our scores were calculated as a mean PRE value of all groups (A1, A2, CG).*

Quantitative All the children correctly solved task 1 (choosing colors of the coding cards). Task 2, that required both choosing the color and the place, was correctly solved by 78% of children. The third task (conditional music reproduction) was solved by 56% of children, and the last task (the correct usage of the pink card) by 61%.

Overall, 36.1% of the children solved all tasks, 33.3% solved 3 of 4 tasks, 19.4% solved 2 tasks, and 11.1% solved only the first task.

Qualitative We present general observations along with the task specific ones.

General observations

SIMULATION. Overall, children did not rely on simulating Robotito's trajectory with their finger to determine the color and placement of the coding cards. However, in certain instances, simulating the path helped them to detect errors or determine the appropriate placement for the next color card.

CARD POSITION IN THE GRID. During tasks 2 and 4, some children correctly selected the colors of the cards but struggled with positioning them on the grid. For instance, they placed the second card too closely to the first one, causing the robot to change direction too soon. Alternatively, they positioned the card next to the robot's trajectory rather than directly within it.

AMOUNT OF CODING CARDS. Some children wanted to create trajectories that required more than the four color cards initially provided. This occurred when they aimed to create longer routes or used "redundant cards," placing two cards of the same color next to each other, even though the second card was unnecessary as it did not alter the robot's movement direction.

MOVING ROBOT IN SPACE. Some children struggled to understand how to use the color cards to move the robot in space. Two children placed the color cards adjacent to each other without considering the colors' meanings, effectively creating "a path from color tiles" rather than using the colors to indicate directions. In some instances, children believed the robot could move diagonally, although this movement is not supported by the robot. Additionally, when asked to demonstrate the robot's movement with their finger, some children indicated that the robot would change direction in locations where no color cards were present.

Task 2

COVERING ROBOTITO. In some cases, task 2 caused confusion among children regarding whether it was correct to cover Robotito's image with a color card. To complete the task, children needed to select a color card to initiate the robot's movements, placing it where the robot was drawn. Some children noted that it was impossible to put the color card beneath the robot and asked questions like, "It [the color card] goes above, or what?" Covering the robot with the first color card caused that the children had to lift it to check the color arrows on the robot and complete the task.

Task 3

This task caused different confusions and led to unexpected solutions.

COVERING COLOR CARDS. Many children tended to place the orange cards on top of the color cards that coded the U-shaped route. In these situations, the evaluator had to indicate that the color cards should not be covered.

IMPRECISE INSTRUCTIONS. In this task the children were asked "Where should we place the orange color cards so that Robotito makes sounds near the sun and is silent near the moon?" (see Figure 3 to visualize the task.) We observed that some children were unsure about what "near the sun/moon" meant in the context of the task. The idea behind the task was to turn on the music mode before the red card (the card closest to the sun) and turn it off before the blue card (the card closest to the moon). However, some children placed the orange cards after these cards, interpreting "near to" more broadly than we intended.

ORANGE CARD FUNCTION. Not all the children understood how the orange card changes Robotito's behavior. Some thought it would change the robot's movement direction, while others believed that the robot would only reproduce sounds when it passes over the card, using it to "make sounds" rather than to activate and deactivate the musical mode. In these cases, children placed only one card close to the sun to "make sounds near the sun." One child thought that to deactivate the musical mode, the orange card should be removed after the robot passed over it and made sounds.

INCORRECT PLACE. Some children tended to place both orange cards together between the color cards. They placed them in the first part of the U-shaped route (between the yellow and red card), in the bottom part (between the red and blue card), or even in the top part of the grid (between the yellow and the purple card), which was not part of the robot's route.

One child placed the orange card outside the grid and used it to cover the drawing of the sun.

Task 4

ALTERNATIVE CARDS. Some children ignored the fact that the robot should start on the pink card and instead tried to build alternative paths. These paths were not executed by the robot as they started with color cards placed next to the robot, but not in its way.

MOVEMENT SIMULATION. Many children simulated the "pink step" (moving one step in the yellow direction then one step in the green direction) to decide where to put the next color card. In some cases, they did not place the next card in the square where the "pink step" ended but instead placed it in the following square.

Summary of Robotito Test results Although all the children appeared to understand the rules that govern the robot's behaviors (task 1 was completed by all of the children), we identified several issues related to correctly positioning the color cards on the grid and misunderstandings robot's capabilities (e.g., moving diagonally, or changing direction without color cards).

We also observed issues arising from the on-paper nature of the test. Children were confused when they had to cover the robot image with the first card in task 2 or they tried to put orange cards on top of color cards in task 3—behaviors that were not observed during ER sessions focused on conditional music reproduction.

Some children used an extra set of color cards to build longer paths or placed "redundant" cards next to each other.

Test results indicated that task 3 was the most challenging for the children. Difficulties arose due to unclear instructions, a tendency to cover the color cards or place both orange cards together, and a misunderstanding of the orange card's function.

In the final task, we observed attempts to "ignore" the pink card, which was defined as the starting point of Robotito's route. In this task, children frequently used finger pointing to define where the robot would stop after executing the "pink step" and placed the following card there.

4.2.4 Correlations between tests

We analyzed the correlation between two validated CT tests to determine if overall scores and scores related to similar CT concepts showed a correlation. Additionally, we sought to validate whether the score of the Robotito Test correlates with the total score of any of the tests.

We calculated the Pearson correlation coefficient (PCC) for data following a normal distribution, and the Spearman rank correlation coefficient (rho) otherwise.

TechCheck-K and BCTt We analyzed the correlation between the general scores, as well as the PRE and POST scores, of both the BCTt and TechCheck-K tests.

The general scores of both tests showed a moderate (almost weak) correlation (rho=0.398). For PRE scores, the correlation was weak (rho=0.294), and the comparison of POST scores indicated a moderate (PCC=0.466) correlation.

Since both tests assess similar CT concepts—TechCheck-K assesses Algorithms while BCTt evaluates Sequences, and TechCheck-K evaluates Control Structures while BCTt evaluates If-then Conditionals—we examined whether the scores for these comparable concepts were correlated. In both cases, the correlation was weak, with rho=0.268 for Sequences and Algorithms and rho=0.189 for If-then Conditional and Control Structures (see Figure 5).

	SEQUENCES	IF	SIMPLE	NESTED	ALGORITHMS	REPRESENTATION	CONTROL
SEQUENCES	1.00	0.30	0.21	0.43	0.27	0.14	0.29
IF	0.30	1.00	0.26	0.35	0.12	0.14	0.19
SIMPLE	0.21	0.26	1.00	0.09	0.16	0.05	0.14
NESTED	0.43	0.35	0.09	1.00	0.07	0.16	0.22
ALGORITHMS	0.27	0.12	0.16	0.07	1.00	0.06	0.19
REPRESENTATION	0.14	0.14	0.05	0.16	0.06	1.00	0.02
CONTROL	0.29	0.19	0.14	0.22	0.19	0.02	1.00

n= 112

P

	SEQUENCES	IF	SIMPLE	NESTED	ALGORITHMS	REPRESENTATION	CONTROL
SEQUENCES		0.0015	0.0229	0.0000	0.0043	0.1497	0.0021
IF	0.0015		0.0048	0.0002	0.2126	0.1367	0.0456
SIMPLE	0.0229	0.0048		0.3433	0.1009	0.5768	0.1405
NESTED	0.0000	0.0002	0.3433		0.4440	0.0913	0.0183
ALGORITHMS	0.0043	0.2126	0.1009	0.4440		0.5613	0.0456
REPRESENTATION	0.1497	0.1367	0.5768	0.0913	0.5613		0.8727
CONTROL	0.0021	0.0456	0.1405	0.0183	0.0456	0.8727	

Figure 5: *Correlations between CT concepts. In the top part we see Spearman's rank correlation coefficients; in the bottom part the p-values.*

For the PRE scores, the correlations were weak (Sequences and Algorithms with rho=0.101 and If-then Conditional and Control Structures with rho=0.175) and statistically insignificant. The POST scores showed a moderate (almost weak) correlation (rho=0.381) in case of Sequences and Algorithms and a weak (rho=0.158), statistically insignificant correlation between Conditional and Control Structures.

BCTt and Robotito Test We conducted a correlation analysis between BCTt scores and Robotito Test scores. Since the Robotito Test was administered after ER activities, we compared its scores only with POST BCTt scores. We observed a moderate (rho=0.634) correlation.

We also analyzed the correlation of BCTt concepts scores with the Robotito Test. Sequences showed significant moderate (rho=0.61) correlation with the Robotito Test results.

We looked for patterns of similar behavior of Robotito Test scores and childrens' responses to questions related to Sequences. We observed that children with high Robotito Test scores (3-4 points) demonstrated improvement in their performance across the first 4 items related to Sequences (see Figure 6, specifically columns Seq1, Seq2, Seq3, and Seq4). These children (n=25) improved their answers in 31% of the cases, maintained correct answers in 57% of the items, maintained wrong answers in 8%, and worsened the answer in only 4%. Specifically, 48% (12 out of 25) of these children improved their scores on the first sequencing task, 24% on the second, 16%

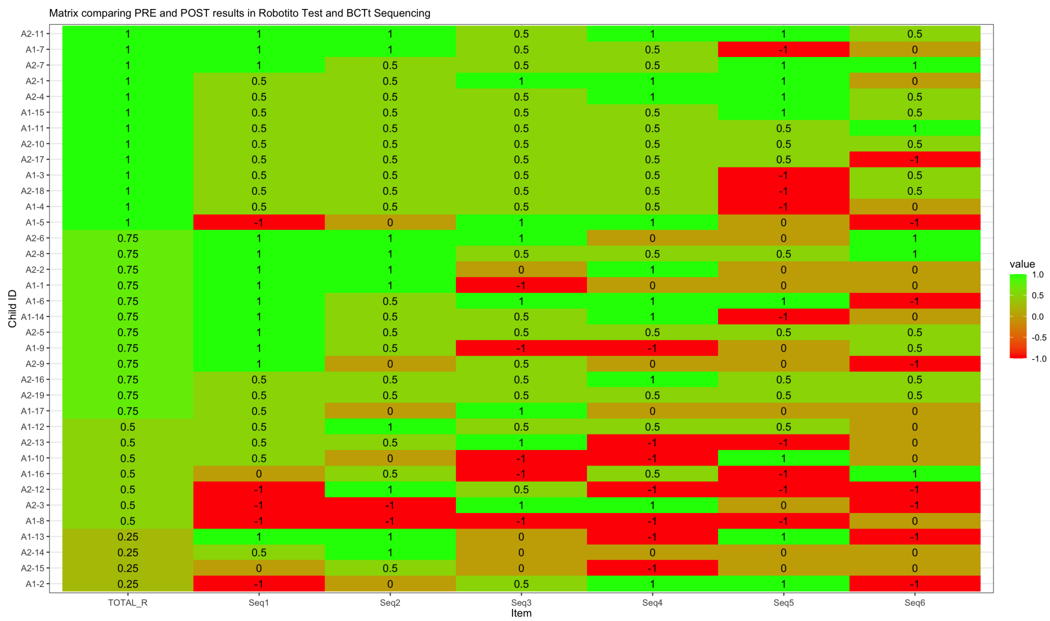

Figure 6: *Robotito Test scores and POST BCTt scores in 6 items related to Sequences. The first column presents Robotito's normalized score, while subsequent columns reflect POST scores coded as follows: 1 for correct answers if the child scored 0 in PRE BCTt test (indicating improvement from incorrect to correct in POST), 0.5 for correct answers if the child scored 1 in the PRE BCTt test (indicating maintenance of correct response), 0 for incorrect answers if the child scored 0 in the PRE BCTt test (indicating maintenance of incorrect response), or -1 for incorrect answers if the child scored 1 in the PRE BCTt test (indicating a decline in score due to incorrect response).*

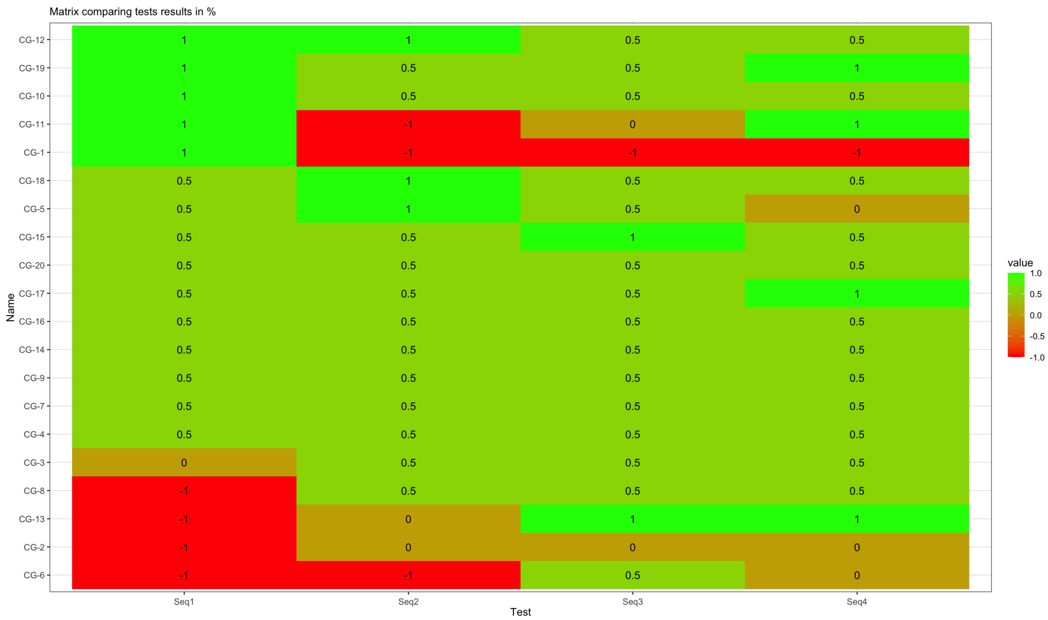

Figure 7: *Robotito Test scores and POST BCTt scores of CG in the first 4 items related to Sequences. The matrix scores were coded as in Figure 6.*

	Seq1	Seq2	Seq3	Seq4
AG-HR	100% (12/12)	67% (6/9)	67% (4/6)	67% (8/12)
CG	80% (4/5)	60% (3/5)	50% (2/4)	57% (4/7)

Table 9: *Improvement index for four initial BCTt Sequencing questions. Comparison between children with high Robotito Test scores from AG (AG-HR) and children from CG.*

on the third, and 32% on the fourth task. We hypothesize that the ER intervention influenced these improvements, as the CG showed lower improvement rates: 25% (5 out of 20) improvement on task 1, 15% on task 2, 10% on task 3, and 20% on the fourth task (see Figure 7).

As the possibility of improvement was lower in the CG due to its better performance in BCTt, we calculated an improvement index for each question. This was done by dividing the number of improved responses (correct responses in the POST-test following incorrect responses in the PRE-test) by the total number of possible improvements (scores of 0 in the PRE-test). This metric revealed that children with high Robotito Test scores outperformed the CG (see Table 9).

Also, the correlation between Robotito Test scores and the sum of the scores of the first four Sequences items showed strong (rho=0.701) correlation.

TechCheck-K and Robotito Test We identified a moderate (rho=0.457) correlation between TechCheck-K POST and Robotito Test scores.

In the case of Algorithms and Representation scores the correlations with the Robotito Test were weak (rho=0.092 and rho=-0.099) and not statistically significant. In contrast, Control Structures showed a significant moderate (rho=0.501) correlation.

Summary of correlations analysis Correlation analysis between TechCheck-K and BCTt scores showed no strong correlation. Similar CT concepts exhibited weak or moderate (almost weak) correlations.

The Robotito Test demonstrated a moderate correlation with both validated CT tests. Upon analyzing CT concepts, moderate correlations were observed between the Robotito Test and Sequenes (BCTt) and Control Structures (TechCheck-K) scores. However, the correlation between Robotito Test scores and the sum of the scores of the first four Sequences items showed strong (rho=0.701) correlation.

4.3 Discussion

The results of our analysis were surprising and left many open questions and future works.

4.3.1 Outperformance of the CG in BCTt

The comparison between AG and CG BCTt scores revealed a significant, but also surprising, difference in favor of the CG, which outperformed the AG, particularly the A1 class. Factorial ANOVA results confirmed a significant difference between AG and CG, especially between A1 and CG. However, there was no significant PRE-POST difference nor any interaction effect between time and group, indicating that the group variable is the sole factor explaining the score differences.

One potential explanation for the surprising difference in BCTt scores could be the class teachers' attitudes observed during interactions with the students. The CG teacher, who had more experience and an established trajectory in kindergarten, maintained the children's patience and focus during activities. She didn't raise her voice to manage inappropriate classroom behaviors. In contrast, the A1 teacher was younger and frequently used an elevated voice and threats to manage the classroom. We speculate that the CG teacher's approach could have influenced the children's attitude during the evaluation, helping them focus on the tasks and reflect calmly on their answers.

Given that the analysis of TechCheck-K scores did not reveal any differences between groups or classes, it is challenging to draw any definitive conclusions regarding differences in CT levels between the AG and CG.

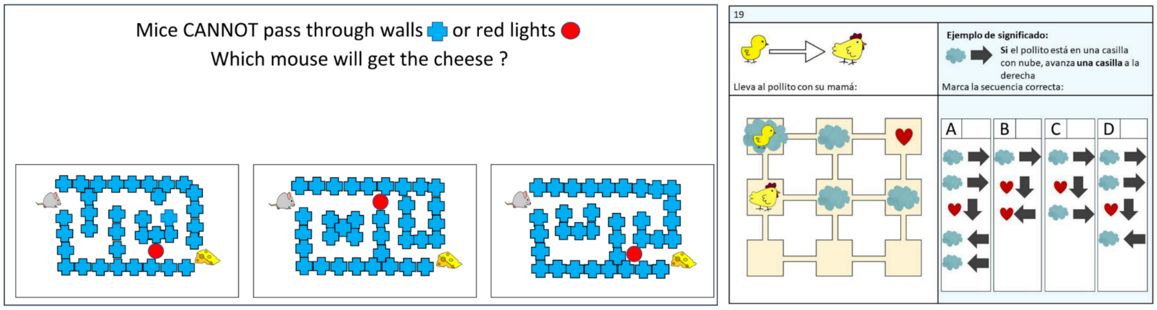

Figure 8: *Examples of items evaluating control structures in TechCheck-K (left) and BCTt (right).*

4.3.2 PRE-POST improvements within groups

Although we observed a generally better performance of the CG in the BCTt test, a PRE-POST comparison did not show any significant improvement in this group. There was no improvement in either BCTt or TechCheck-K scores, leading us to conclude that while the CG had a higher initial level of CT according to BCTt scores, it did not improve its performance in any test. In contrast, the AG, particularly the A2 class, significantly improved its BCTt scores. However, this improvement was not reflected in the TechCheck-K scores, making it difficult to determine if the AG truly improved its CT level.

Furthermore, at the level of specific CT concepts, we found disjunctive results. While the If-then Conditional score of BCTt improved in the CG, its corresponding concept in TechCheck-K, the Control Structures, showed an improvement in the other group, the AG.

The way the concept of control structures was represented in both tests (see Figure 8) could have influenced the results. Although both tests focused on if-then rules, they were incorporated differently. In the BCTt, children had to follow a programming sequence from top to bottom and analyze each if-then rule to determine if they could move the baby chicken in the grid. In contrast, in the TechCheck-K, the if-then rules were fixed and defined from the beginning of the task and had to be used to analyze the mazes. In the case of BCTt the rules could change as the chicken progresses through the grid. For example, in the answer A in Figure 8, standing on the cloud in the first rule makes the chicken move right, while in the last rule, it makes the chicken move left. This makes the task more complex than simply applying the same rule consistently. We observed differences in the percentage of correct answers that confirm BCTt tasks were more difficult: the If-then Conditional tasks of BCTt scored 50% (Item 7) and 29% (Item 8), while the Control Structures of TechCheck-K scored 84% (Item 8) and 73% (Item 9).

Based on this, we could explain the divergent progress results by assuming that the AG mastered the if-then concept at a less difficult level, while the CG mastered more complex if-then rules. This discrepancy could also account for the weak and statistically insignificant correlation between the two concepts revealed by the correlation analysis.

4.3.3 Comparison with other studies

Comparison with other studies showed strong correlation of our results with the correct response rate of each item reported in [30] and [18].

Although the scores of each item reported by Zapata et al. [30] are higher than our scores, this difference could be explained by the fact that their data encompassed children aged 5 to 8. Despite their higher scores, there is a high correlation with our results, confirming similar performance among the groups.

Some differences were observed when analyzing correct responses rates grouped by concepts. Since we compared only two numbers, no statistical analysis was possible; therefore, we could only express our subjective judgments. Regarding BCTt concept scores, they were similar to those reported by Zapata et al. [30] and Zapata-Cáceres and Fanchamps [31], showing particularly high similarity with the latter, which reports data for 5-year-old children.

Relkin and Bers [18] scores of each item were of similar magnitudes as our results, but the percentages of correct answers for each CT concept reported by Relkin et al. [20] were slightly lower for Algorithms and Representation and considerably lower for Control Structures compared to our results. Although our group showed a similar mean age (6.02 vs. 5.86 in [20]), they reported that the minimum age in their kindergarten group was 4. The inclusion of 4-year-old children in their sample could have influenced their scores. Lin et al.'s scores [14] were slightly higher than ours and Relkin et al.'s results, despite working with younger children who had a mean age of 5.51.

Given that the differences in scores were generally small and the correlation was strong, we consider that the groups performed similarly.

4.3.4 Correlation between the validated PC tests

Currently, there are only two validated CT tests, with few studies reporting their use in our age group, and no studies that report the use of both tests while analyzing the outcomes. As previously mentioned, we observed many contradictory results (see Table 10), raising the question of whether both tests measure the same ability.

Although we reduced the number of issues in each test, excluding concepts that the ER activities did not address, we expected the total scores of both tests to correlate, meaning that children performing well on one test would also perform similarly on the other. As Na et al. [15] pointed out, both tests are effective in discriminating between children with the same level of CT (to be precise between children with relatively low CT level), therefore we expected similar test results. Moreover, we anticipated that similar concepts would yield similar scores. However, statistical analyses revealed no strong correlation between the overall test scores or between scores of similar CT concepts (Sequences vs. Algorithms, If-then Conditional vs. Control Structures).

Comparison	BCTt	TechCheck-K
AG-CG scores (two-way t-test and factorial ANOVA)	X	-
A1-CG scores (two-way t-test and factorial ANOVA)	X	-
AG PRE-POST (paired t-test)	X	-
A2 PRE-POST (paired t-test)	X	-
If-then Conditional CG PRE-POST (Wilcoxon signed-rank test for paired data)	X	-
Control Structures AG PRE-POST (Wilcoxon signed-rank test for paired data)	-	X

Table 10: *Contradictory results across validated CT tests. Significant outcomes marked with the cross.*

The differences between BCTt and TechCheck-K results could be explained if our results showed a high discrepancy with other studies, indicating that our sample might not be representative. However, this is not the case, as our results showed a strong correlation with the studies already published by the authors of the tests.

These observations raise questions about the differences between the tests, which result in different scores within the same population. Further research is needed to delineate these differences, enabling researchers to select the most appropriate test for their specific research questions.

4.3.5 Correlations between the validated PC tests and Robotito Test

The Robotito Test results exhibit only weak to moderate correlations with the general scores and concept scores of validated computational CT tests[7]. The strongest correlations, though still moderate, were observed between the BCTt and the Robotito Test scores and between the Robotito Test scores and Sequences concept scores.

We noted that children with high Robotito Test scores demonstrated improvements in their responses to initial Sequences tasks. Statistical analysis revealed a strong correlation between the total score of the first four Sequences items and the Robotito Test scores. This finding suggests that the Robotito Test score may be indicative of children's abilities related to easy and moderate sequencing tasks.

4.3.6 ER activities impact

Validated CT tests showed contradictory results, making it challenging to draw definitive conclusions about the impact of ER activities with Robotito on children's CT development. According to BCTt results AG significantly improved its scores, but this finding was not confirmed by TechCheck-K results. Improvements related to Control Structures and If-then Conditional were also inconsistent.

[7]Since the Robotito Test was administered after the ER activities, we conducted the correlation analysis using the POST scores of the validated tests.

The Robotito Test results indicated that all the children understood the color-direction relationship essential for comprehending the robot's behavior, with more than half of the AG correctly solving each task. Additionally, children with high Robotito Test scores showed improvement in initial sequencing tasks of the BCTt. Students were able to plan trajectories for the robot, divide the route into smaller parts, and translate it into sequences of color cards. These observations suggest that the intervention was successful; however, the contradictory results from validated instruments prevent us from drawing definitive conclusions.

We identified two important aspects to consider for future activities to avoid surprises and confusion: study design and evaluation format. The unexpected outperformance of the CG and differences in performance across AG classes highlight the importance of random assignment to AG and CG for a fair comparison. Although random assignment was not feasible in this study due to the different class schedules, future studies should strive to implement it to complement the existing data. While this may be challenging in a kindergarten context, studies in informal settings could complement current results with additional data from more controlled experiments.

We also believe that the on-paper evaluation format used to validate knowledge about the concepts introduced in ER sessions may have caused some unnecessary confusions. During the Robotito Test, some children covered the color cards to activate or deactivate the musical mode, a behavior never observed with the real robot. Additionally, covering Robotito with the color card in task 2 was both surprising and problematic for the children. They were not accustomed to placing the color cards over the robot, and after doing so, they could not see the color-direction indicators on top of the robot. Consequently, they had to lift the first coding card to proceed with the task, which caused further confusion. Since the evaluation was conducted individually and by a single evaluator, using the real robot should not introduce significant differences. It may, however, result in a slightly longer evaluation time for each child.

4.3.7 Conditionals

Conditionals are present in both validated CT tests, indicating their significance in CT. Therefore, we believe they should be specifically targeted during ER activities aimed at developing CT.

However, there are scarce studies that report on ER activities that introduce conditionals to preschoolers and measure the impact. In our previous work [2], we identified only one empirical study [26] providing evidence of children mastering conditionals. Through additional literature review, we were able to identify another study reporting pre and post BCTt scores related to If-then Conditional [31]. Both studies confirm that preschoolers can solve tasks using conditional statements, although Zapata-Cáceres and Fanchamps [31] noted that this concept was not accessible to children younger than 5.

Given that there are only two empirical studies, with one admitting that teachers may have provided more help and scaffolding than intended during the evaluation [26], we believe our results contribute to the discussion on whether preschool children can understand and successfully use conditionals.

The results of the present study show promising findings related to the understanding and correct use of conditionals. Both validated tests indicated already in the PRE test, that children could solve tasks based on if-then statements. For BCTt items evaluating If-then Conditional, 50% of the children correctly solved Item 7, and 29% solved Item 8. TechCheck-K showed much higher scores for Control Structure items, with 84% correct answers for Item 8 and 73% for Item 9. Additionally, task 3 in the Robotito Test, which evaluates conditional music reproduction, was correctly solved by 56% of children. We believe this score could be higher, as issues such as imprecise instructions and problems related to the on-paper format of the evaluation caused some confusions.

Previous studies and our results appear to confirm that conditionals are accessible for children aged 5 to 6. We believe that ER interventions should include activities focused on conditionals to provide children with an opportunity to master more advanced programming concepts. This foundation will enable them to build complex algorithms in the future.

5 Conclusions

In this study, we reported two stages of developing conditionals in Robotito and implementing them in Robotito's curriculum.

In the first step, we explored various prototypes for incorporating conditionals into Robotito's programming. The prototypes included the color frame, musical mode, and split card, each offering distinct implementations of conditionals. Through multiple evaluations involving experienced teachers, we identified the strengths and weaknesses of each prototype. The color frame prototype was deemed too complex, while the musical mode and split card were found to be more accessible for preschoolers. The musical mode, in particular, was favored for introducing a new output modality—sound.

One of the tools used in our evaluations was Robotito's simulator. Teachers highlighted the simulator's value as a tool for introducing Robotito and working on programming tasks in a less distracting environment before using the real robot.

Taking into account the insights from the evaluation activities, we incorporated conditional music reproduction and Robotito's simulator based activities into Robotito curriculum and conducted a field study with level 5 preschoolers.

The activities were tested in two kindergarten classes, demonstrating that the children were able to understand and apply Robotito's rules to solve programming tasks during the classroom activities and in the final evaluation with Robotito Test. Also, potential improvements of Robotito Test were discussed.

The Robotito Test's evaluation of conditionals, along with the pre-test results of CT tests, showed that the children were capable of understanding and applying conditional statements to solve the proposed tasks. This suggests that conditionals can be introduced through ER activities already at the age of 5.

The analysis of scores from two validated CT tests revealed a lack of correlation and no similarities in scores between similar CT concepts. In some cases, the results were not only diverse but also contradictory. This highlights the need for further research to better understand the differences between the tests and the contexts in which they are appropriate.

Our study provides a unique data source that can be used for further analysis and comparisons with other experimental data. As our results support the accessibility of conditionals for 5 and 6-year-old children, we hope they will encourage the inclusion of this concept in ER curricula.

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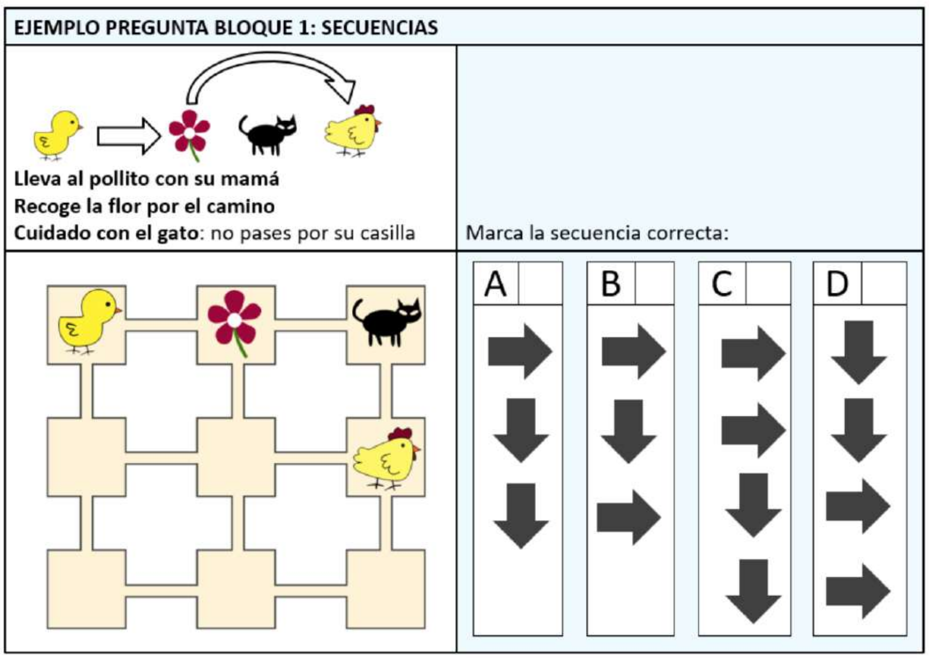
Appendices

A BCTt tailored for our study

Madrid – febrero 2020 BCTt- Test de Pensamiento Computacional



maria.zapata@urjc.es, estefania.martin@urjc.es

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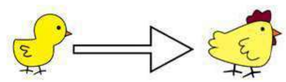

Lleva al pollito con su mamá:

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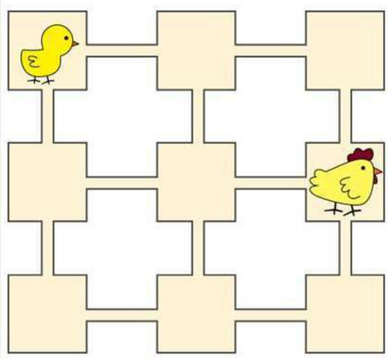

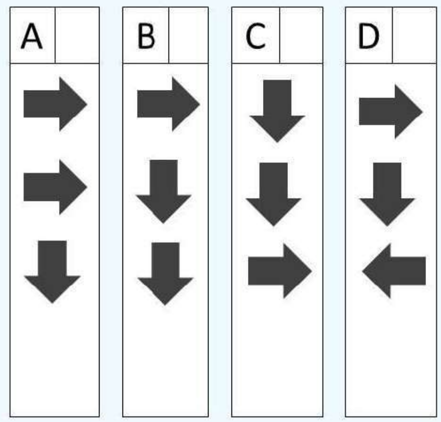

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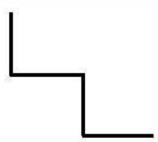

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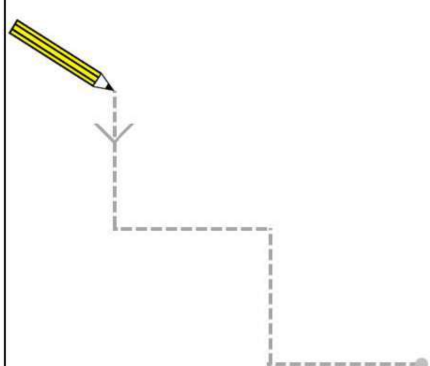

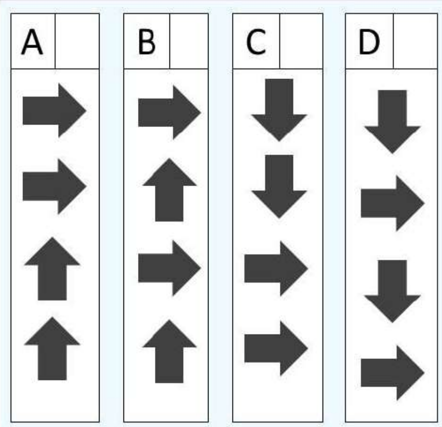

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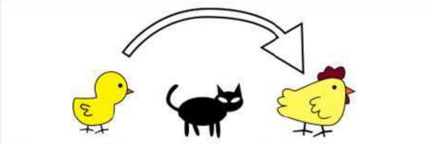

Lleva al pollito con su mamá.
Cuidado con el gato: no pases por su casilla

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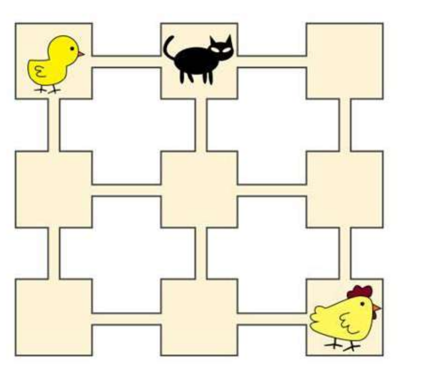

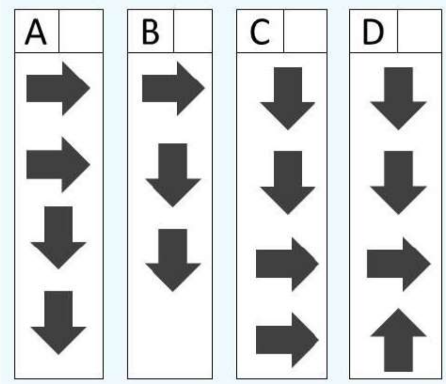

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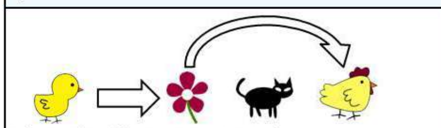

Lleva al pollito con su mamá
Recoge la flor por el camino
Cuidado con el gato: no pases por su casilla

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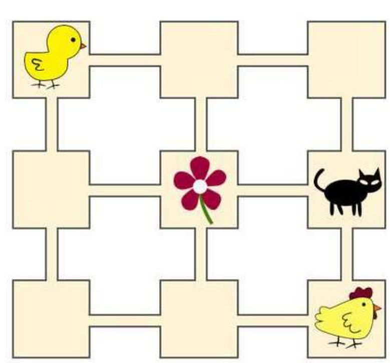

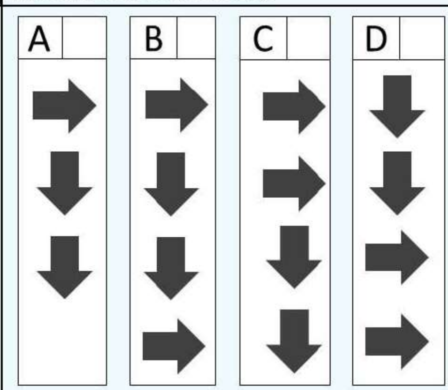

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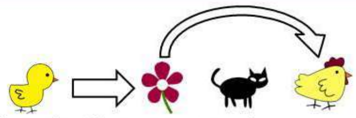

Lleva al pollito con su mamá
Recoge la flor por el camino
Cuidado con el gato: no pases por su casilla

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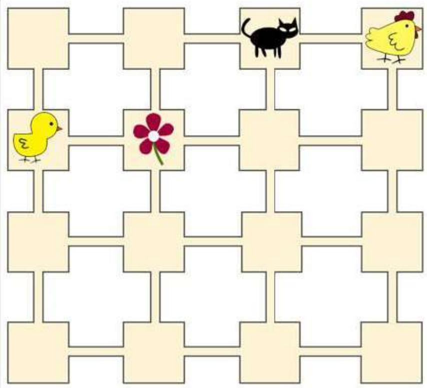

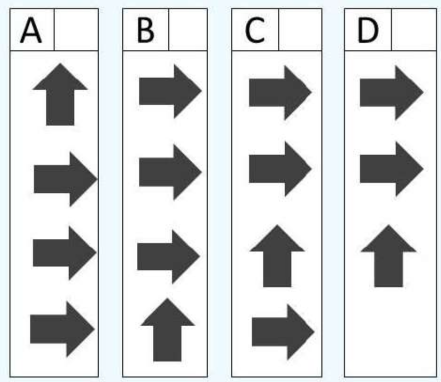

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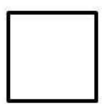

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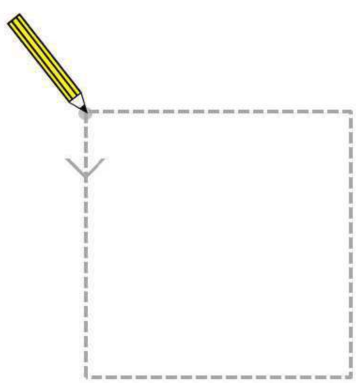

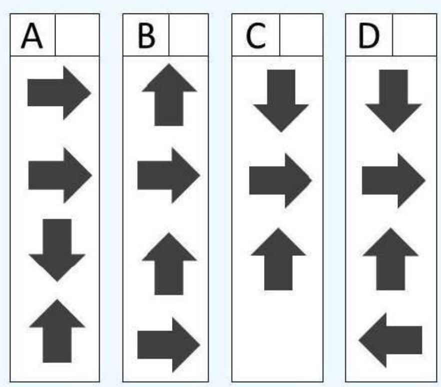

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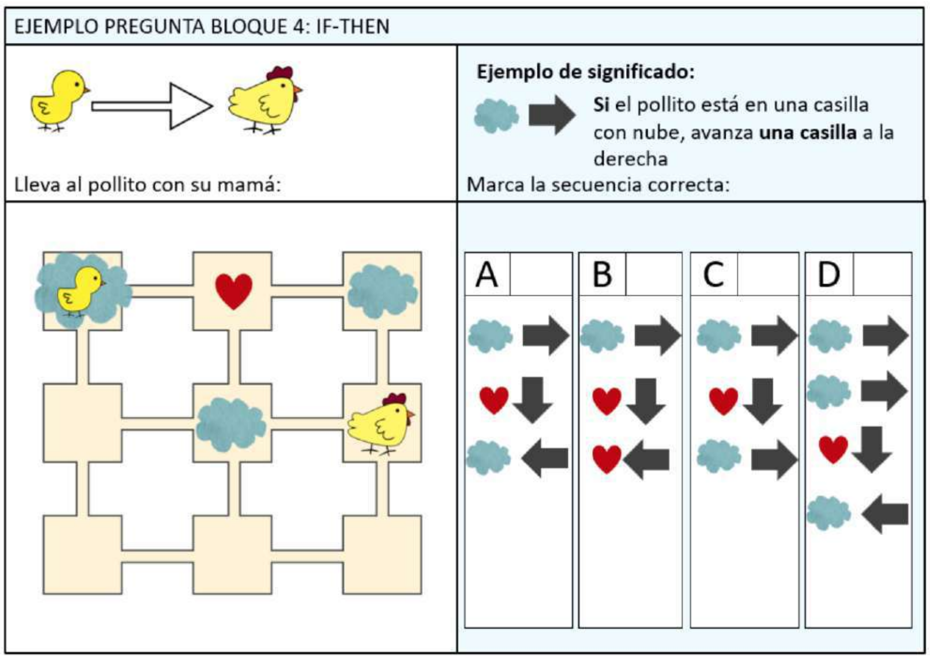
EJEMPLO PREGUNTA BLOQUE 4: IF-THEN
Lleva al pollito con su mamá:
Ejemplo de significado:
Si el pollito está en una casilla con nube, avanza una casilla a la derecha
Marca la secuencia correcta:
A
B
C
D

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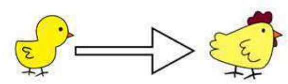

Lleva al pollito con su mamá:

Ejemplo de significado:

Si el pollito está en una casilla con nube, avanza **una casilla** a la derecha

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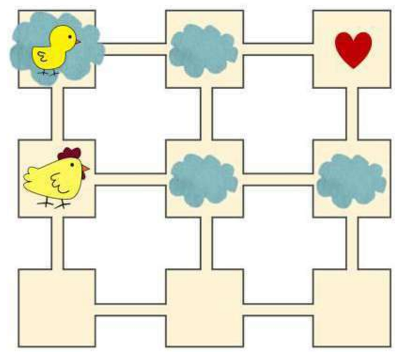

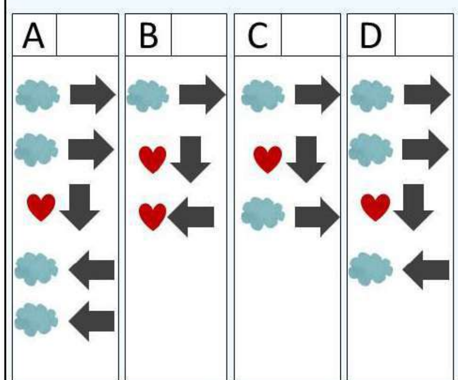

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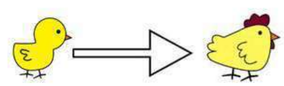

Lleva al pollito con su mamá:

Ejemplo de significado:

Si el pollito está en una casilla con nube, avanza **una casilla** a la derecha

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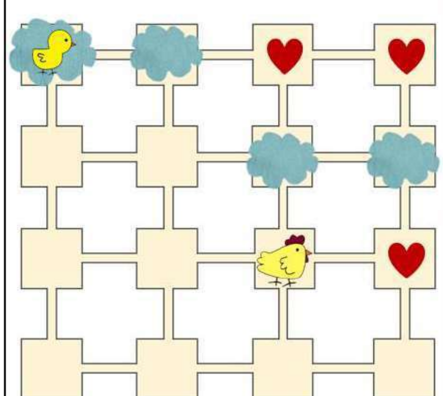

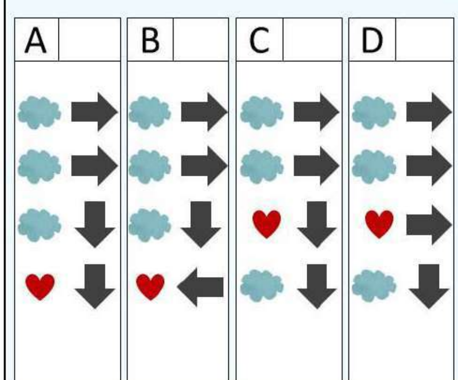

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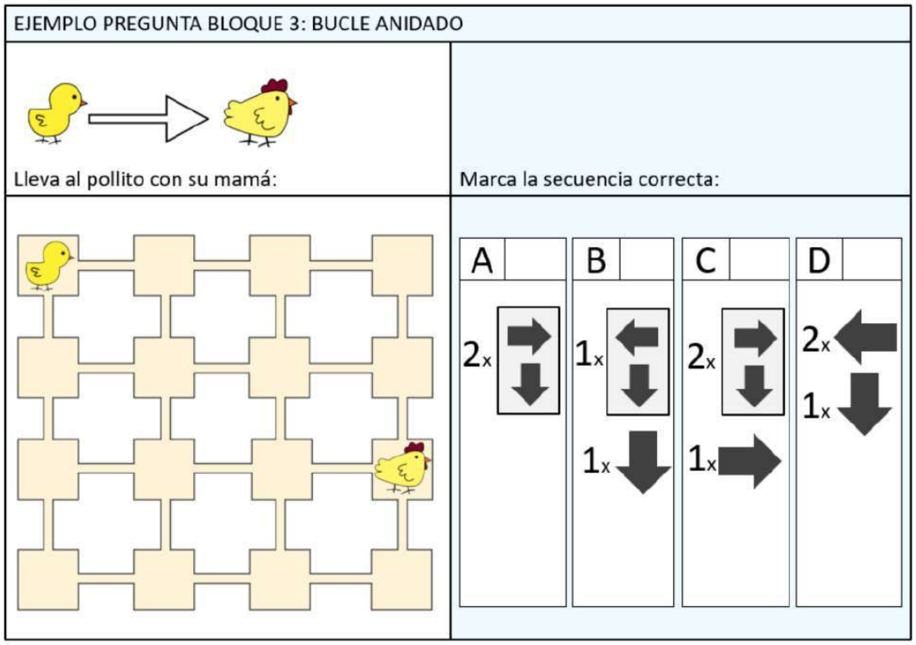

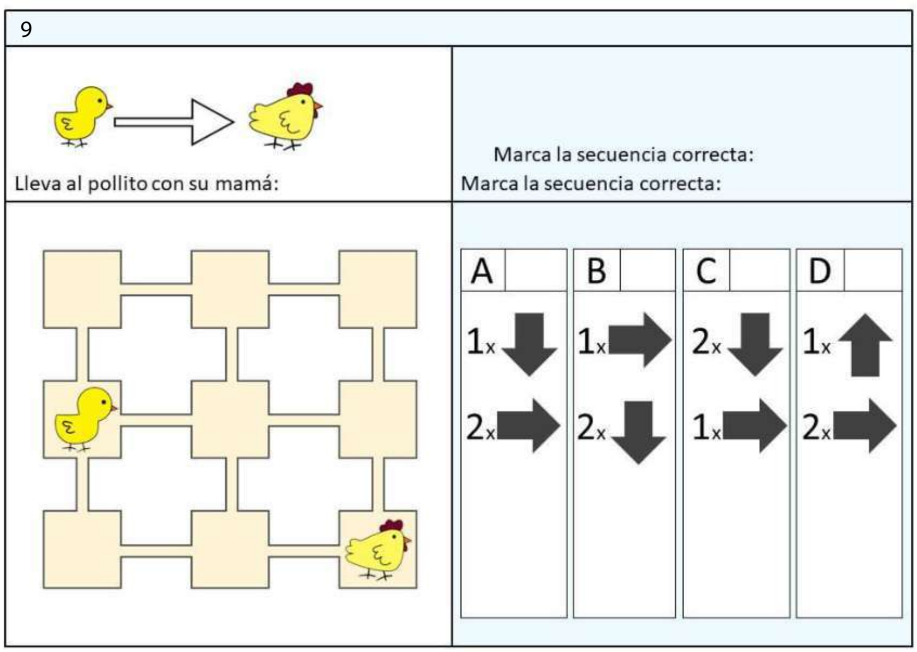

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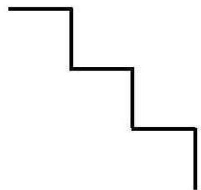

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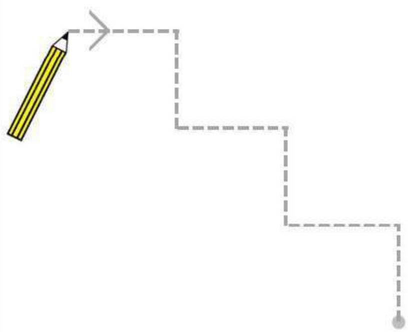

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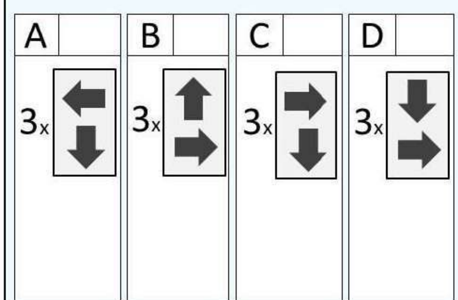

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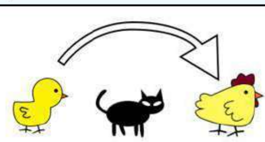
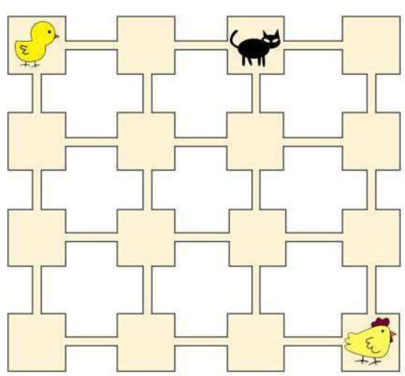


Lleva al pollito con su mamá.
Cuidado con el gato.



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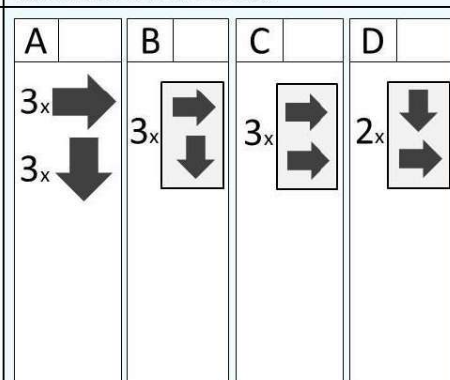

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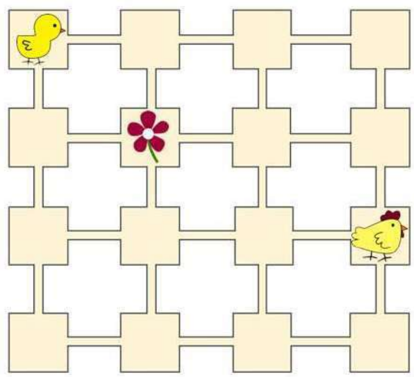
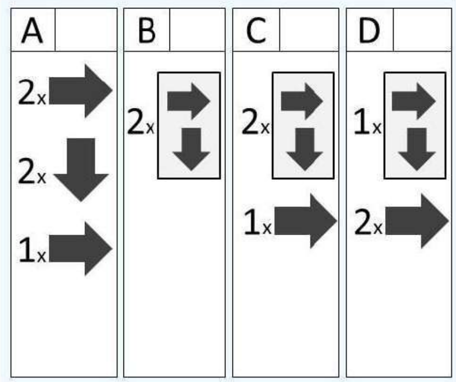
12

Lleva al pollito con su mamá
Recoge la flor por el camino

Marca la secuencia correcta:





13

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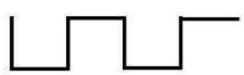

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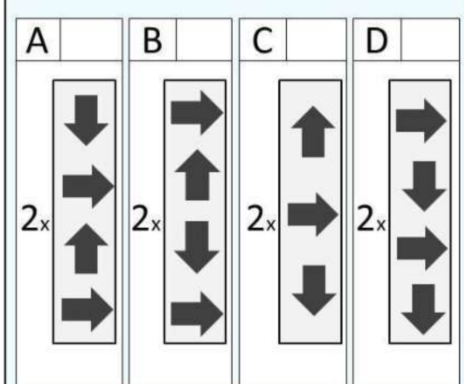


maria.zapata@urjc.es, estefania.martin@urjc.es

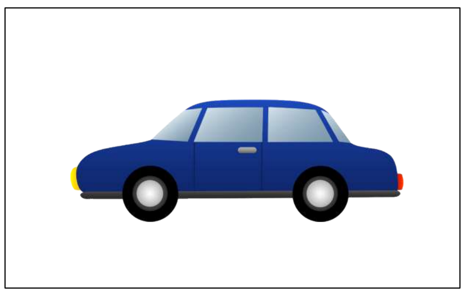
B TechCheck-K tailored for our study

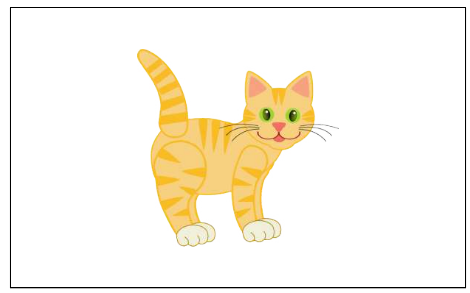
-Práctica 1-

¿Qué cosa se puede comer?

-Práctica 2-

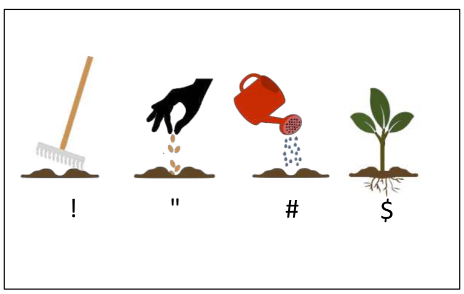
¿Cuál es un animal?

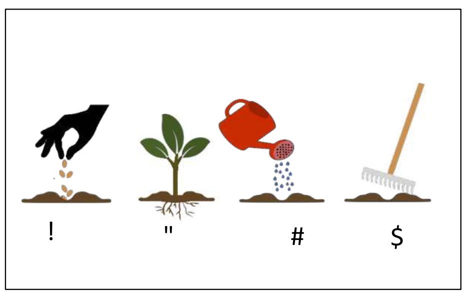


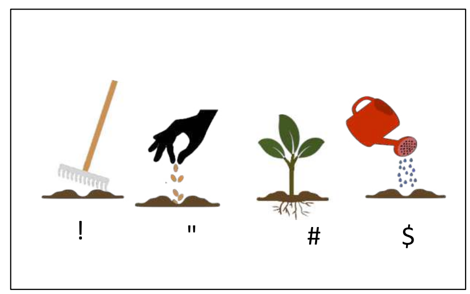


-1-

¿Cuál es el orden correcto para cultivar una planta?



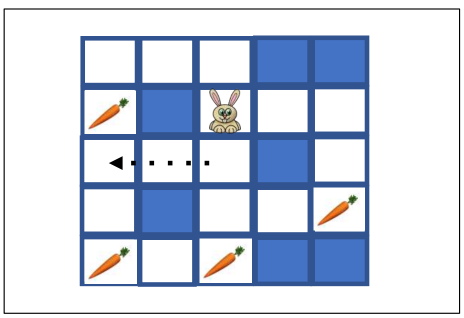


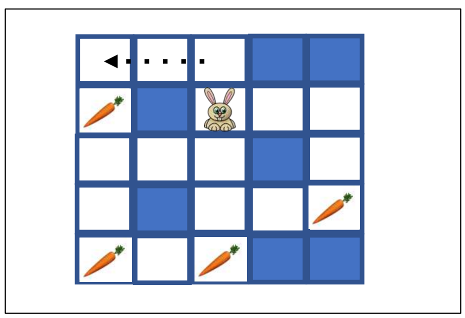


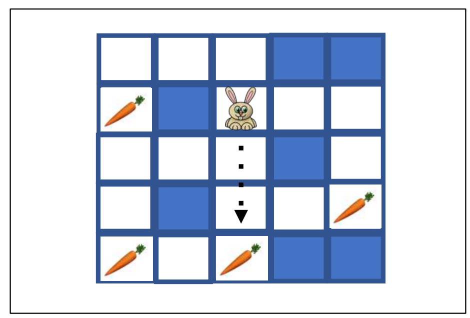
-2-

El conejito solo puede saltar un cuadrado blanco a la vez.

¿Cuál es la forma más rápida para que el conejito consiga UNA zanahoria?

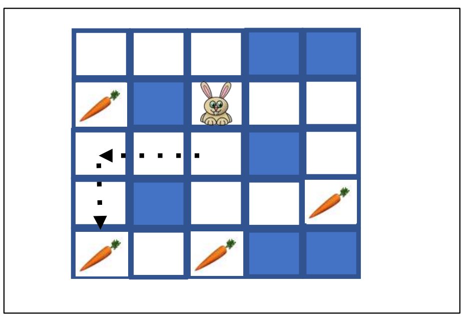


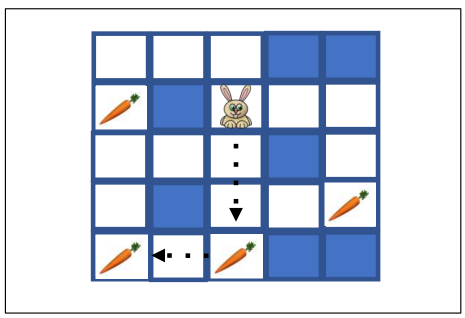


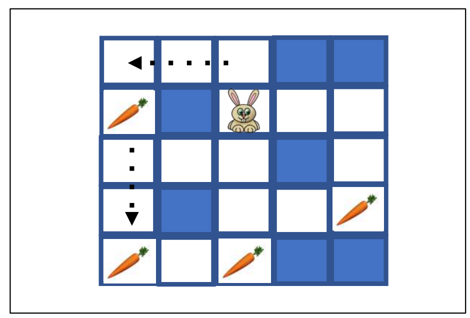


-3-

El conejito solo puede saltar un cuadrado blanco a la vez.
¿Cuál es la forma más rápida para que el conejito consiga DOS zanahorias?

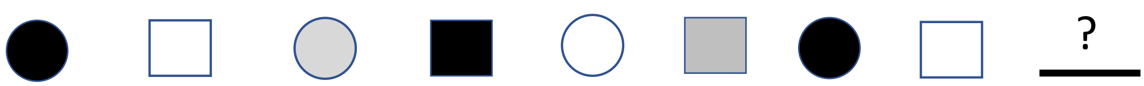


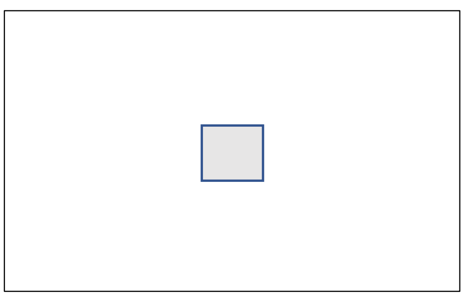


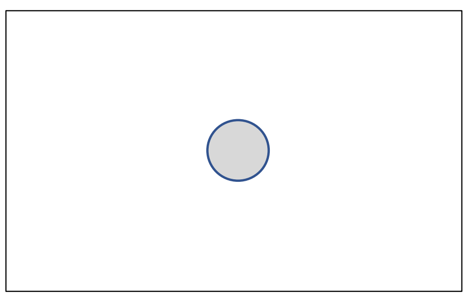


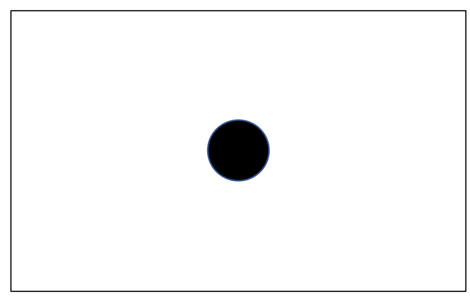
-4-

¿Qué viene a continuación?



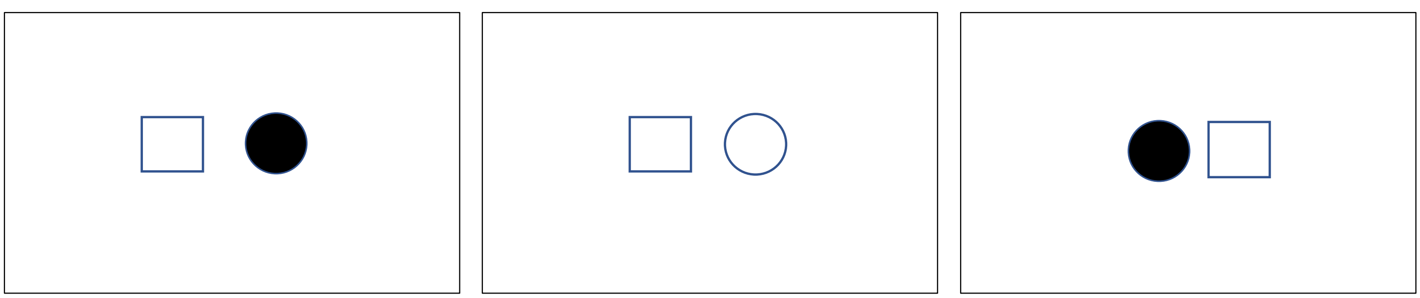






-5-

¿Qué viene a continuación?



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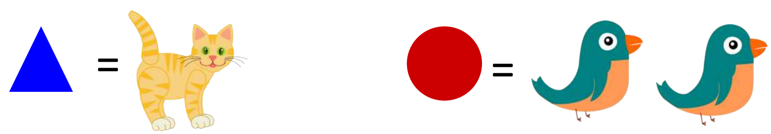
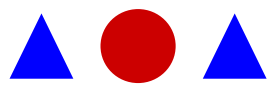
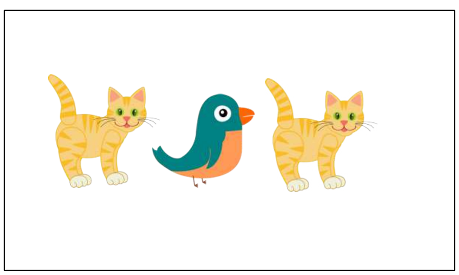
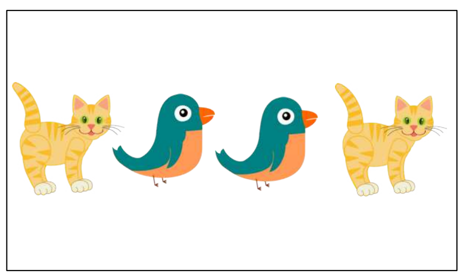
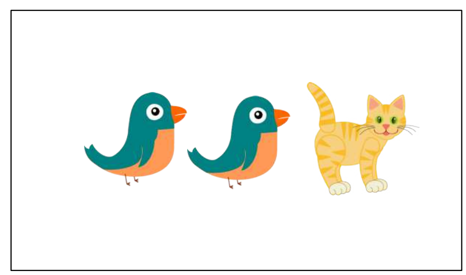


Si un triángulo representa un gato y un círculo representa dos pájaros, ¿qué representan estas tres formas?

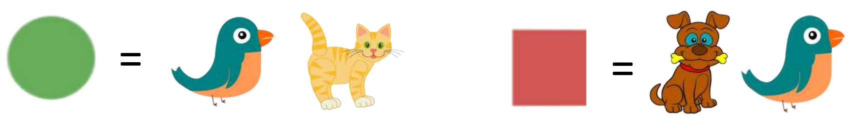




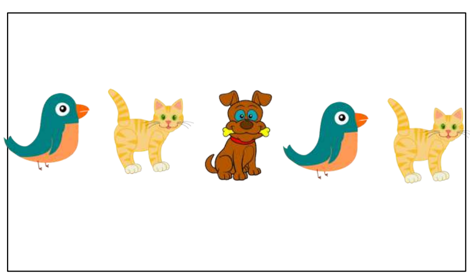


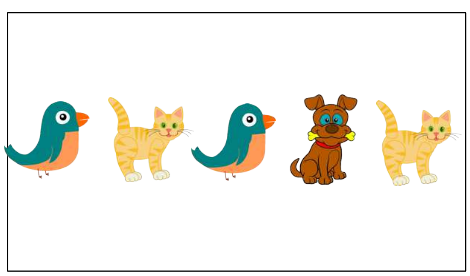


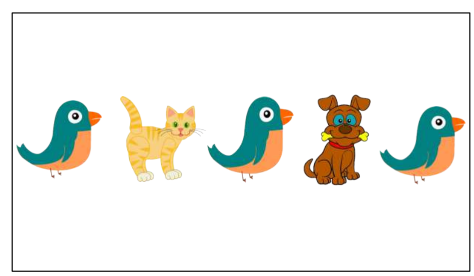
-7-



Un círculo representa un pájaro y un gato. Un cuadrado representa un perro y un pájaro.
¿Qué representan estas figuras?



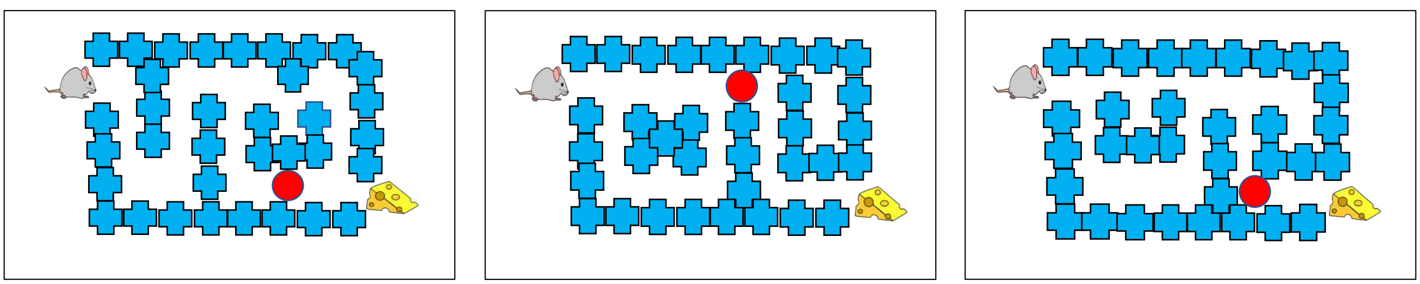




-8-

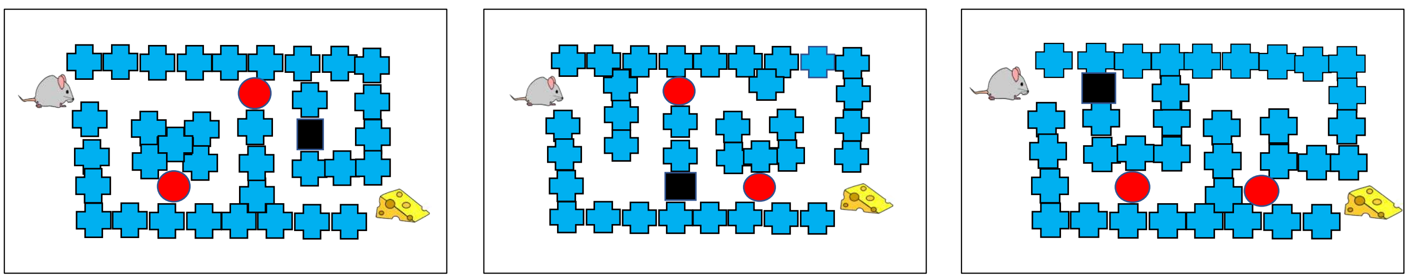
Los ratones NO pueden atravesar paredes o luces rojas

¿Qué ratón conseguirá el queso?



-9-

Los ratones NO pueden atravesar paredes o luces rojas , pero SI pueden atravesar túneles negros . ¿Qué ratón conseguirá el queso?



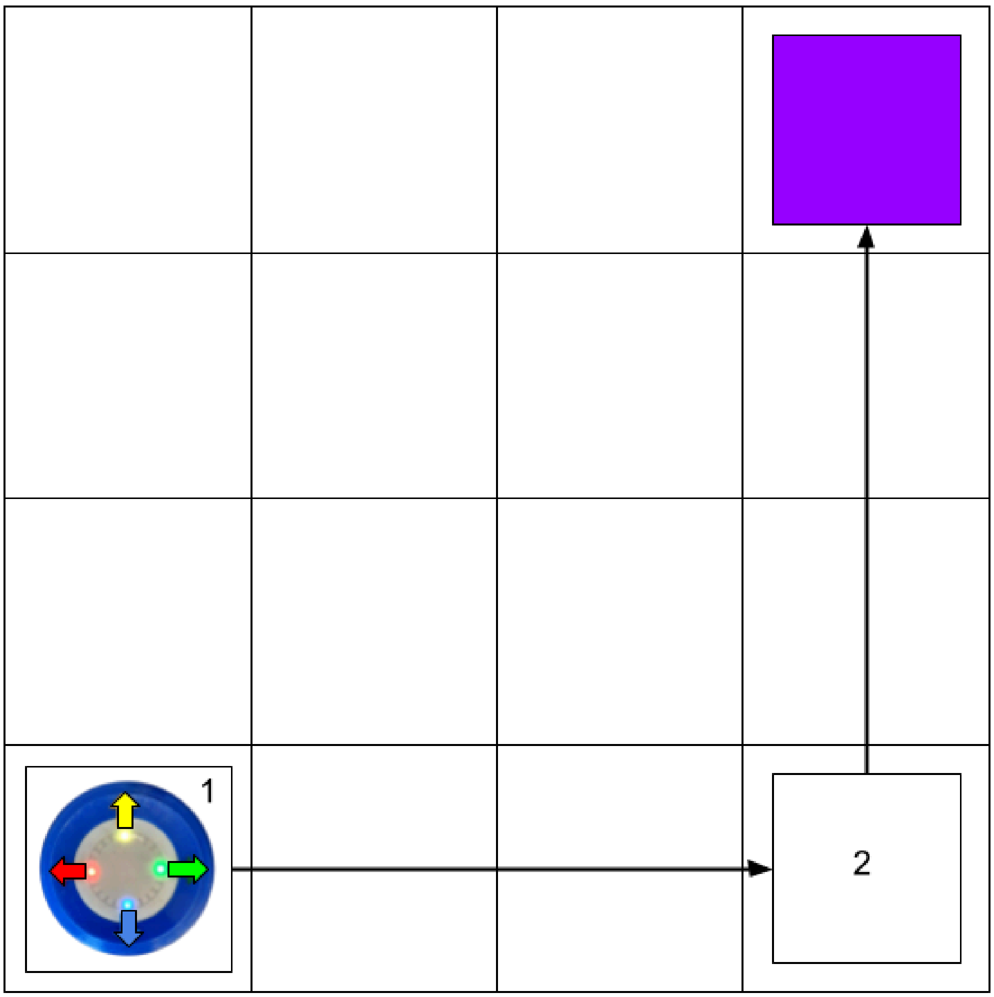
C Intervention's rubric

- Activity context (Options: formal, informal): FORMAL
- Number of participants (Number): 56
- Modality of work (Options: individual, group-based, mixed): MIXED Number of participants per group (Number): HALF CLASS OR 1 to 3
- Type of activity (Options: goal-oriented, open-ended, mixed): MAINLY GOAL-ORIENTED
- Free-play (Options: yes, no): NO
- Activity duration
  - Number of sessions (Number): 8
  - Session duration (Number in minutes): 30 to 75 minutes
  - Sessions' frequency (Number per week): 0 to 3
- Adults guiding the activities
  - Number (Number): 1 or 2
  - Adult–child ratio (Number): 1-WHOLE CLASS, 1-HALF CLASS, 1-SMALL GROUP (1 TO 3)
- Scaffolding provided
  - Adults' support (String with description of the type and degree of support): GUIDING QUESTIONS
  - Narrative (String with description): NO
  - Auxiliary objects (String with description): 4X4 MAT, COLOR CARDS, BLOCKING CARDS
  - Embodied examples (String with description): PLAYING TO BE ROBOTITO
  - Others (String with description): ROBOTITO SIMULATOR USED ON TV
- Unplugged activities (String with description): DRAWING ROBOTITO, ON-PAPER TASKS (COLORING OR DRAWING CODING CARDS)
- Explicit error detection (Options: yes, no): NO
- Relation with other domains (String with description): NO
- Communicating, sharing, and creating community (Options: yes, no): AT THE BEGINNING OF THE FIRST THREE SESSIONS

D Robotito Test

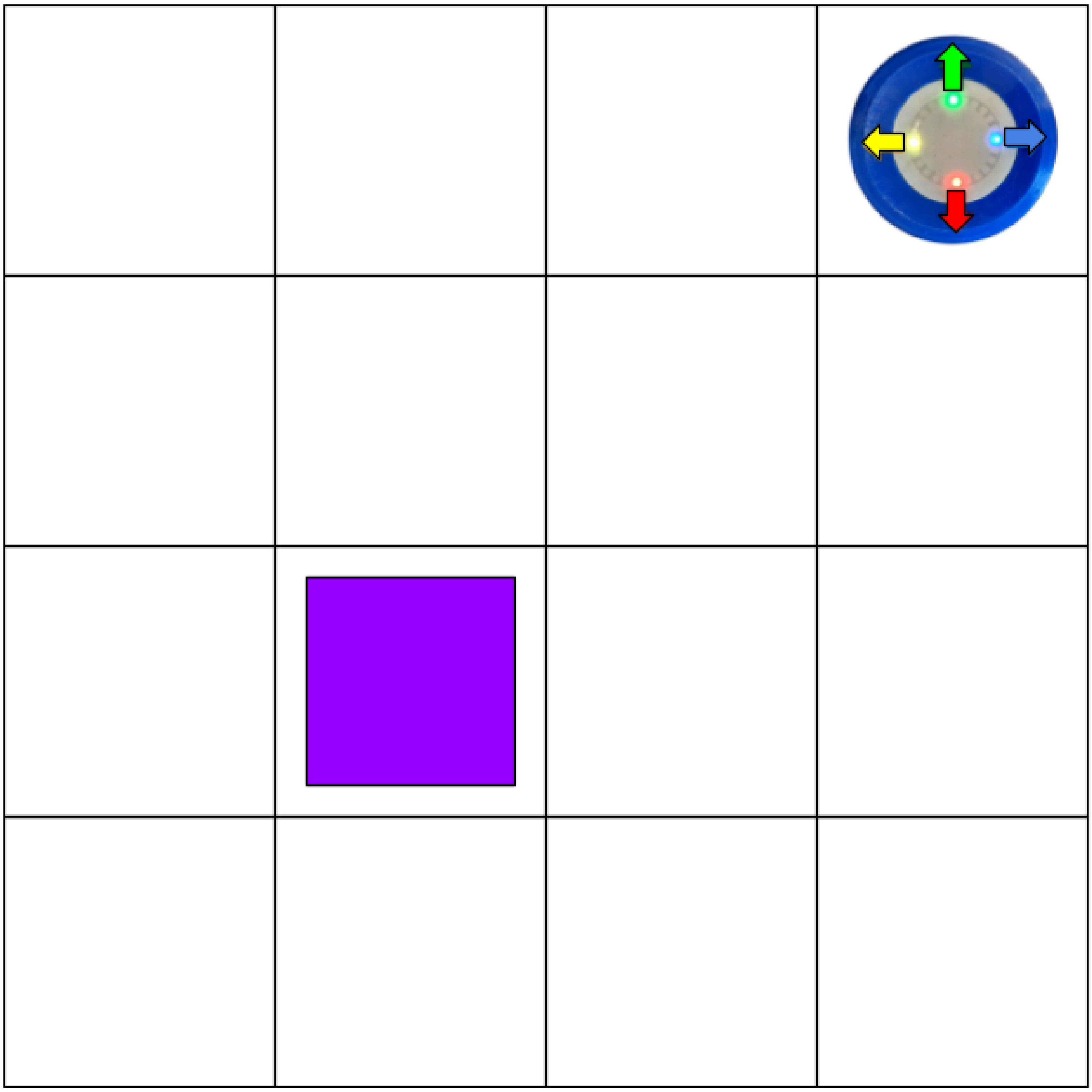
Tarea 1

¿Qué color (amarilla, roja, verde, azul) deben tener las tarjetas 1 y 2 para que el Robotito llegue a la tarjeta violeta?



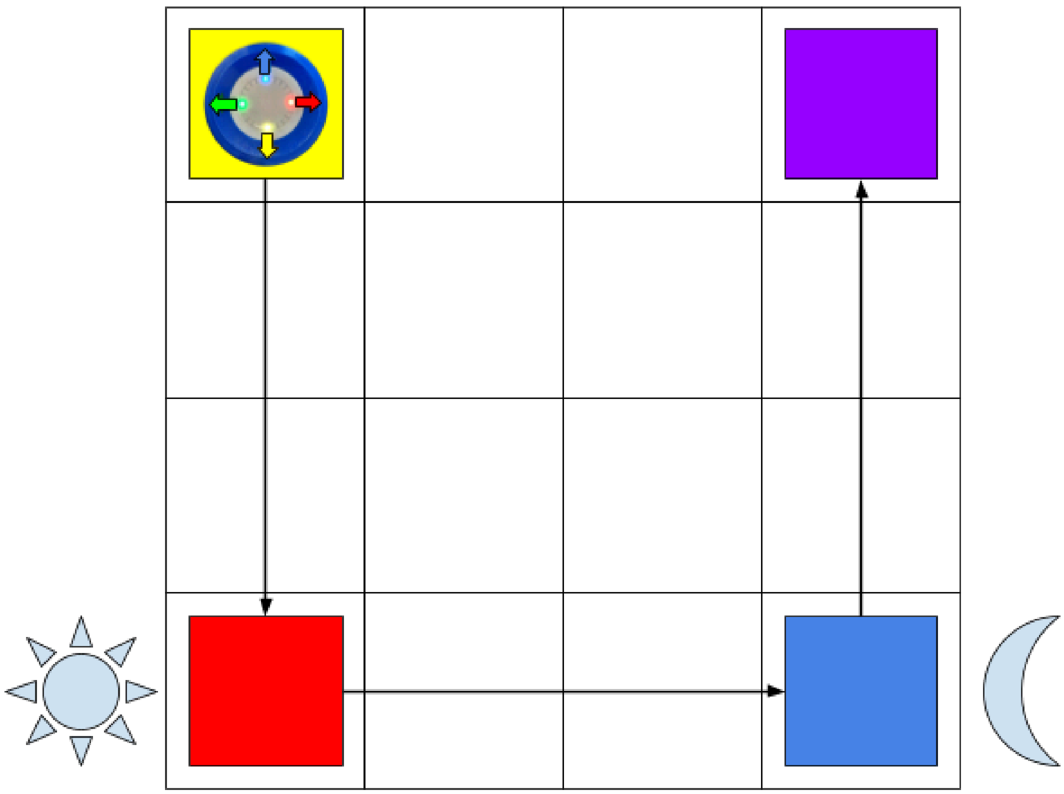
Tarea 2

Poné las tarjetas para que el Robotito llegue a la tarjeta violeta. Selecciona de qué color deben ser y en qué lugar ponerlas.



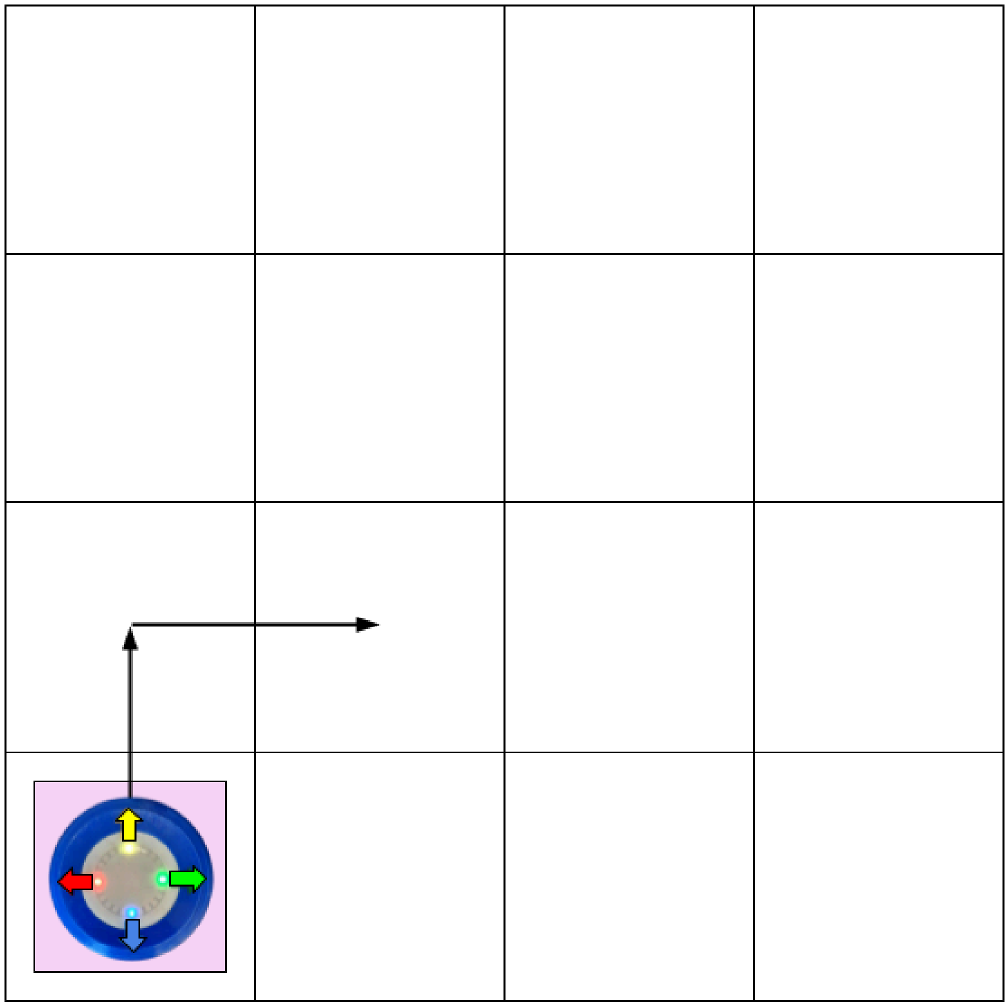
Tarea 3

El Robotito va a dar un paseo para llegar a la tarjeta violeta. En el camino debe pasar haciendo sonido cerca del sol y sin sonido cerca de la luna. ¿Dónde debemos colocar las tarjetas de color naranja para que el Robotito haga sonidos cerca del sol y no los haga cerca de la luna?

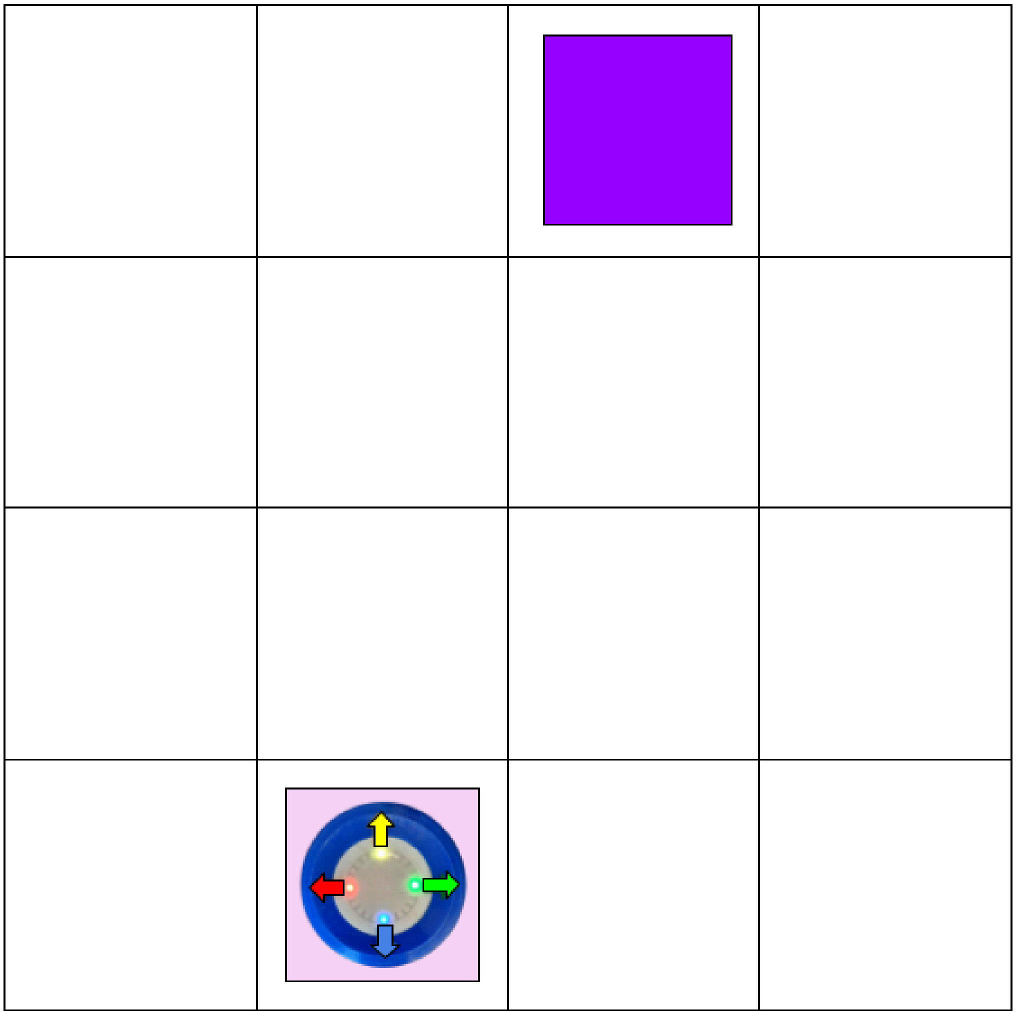


Tarea 4

El Robotito usa la tarjeta rosada para ir adelante y para el costado derecho.



Robotito empieza en la tarjeta rosada, ¿qué tarjeta hay que agregar y dónde para que llegue a la tarjeta violeta?



E Activities

Activity #1 Total time: 40 minutes. We asked the children to reflect on what the robots are and discussed with them the ideas. Each child explored Robotito (robot turned off) and we talked about what they observed (its parts, materials). We turned on Robotito and thought about how to control it. We explored how it moves with yellow, red, green and blue color cards and fixed the color paper arrows on the top of the robot to indicate the directions in which the robot moves after sensing a specific color.

Activity #2 Total time: 60 minutes. First, we reviewed the components of Robotito and its responses to color cards. Next, we explained that the activity would be conducted in two groups: one group would draw, while the other would role-play as Robotito, with roles switching afterward. For the drawing activity we provided three Robotitos: two normal robots and one without the shell to observe the inner parts of the robot.

The group that was playing to be Robotito was divided in pairs. One pair acted in front of the rest of the children that observed from their chairs. One child from each pair was acting as Robotito, the other as a programmer that places the color cards on the floor to move the robot. The idea was to direct the robot without hitting the furniture or the classmates. After a while of playing, the children switched the roles. After one pair went through playing robot and programmer, the next pair was called to perform in front of the others.

Figure 9: *Three moments of Activity #3. From left to right: child selecting were to place the robot with fixed orientation to reach the opposite site of the mat; child selecting a color card that will be placed on the floor to avoid that the robot escape from the circle formed by the children; child rotating the robot to reach the purple card.*

Activity #3 Total time: 60 minutes. We discussed the drawings done in the previous session. We splitted the group in two. Each group worked with one researcher on the same activity—the children were divided in two teams; each team sat on the opposite side of the mat. In the first part of the activity the children had to direct the robot to

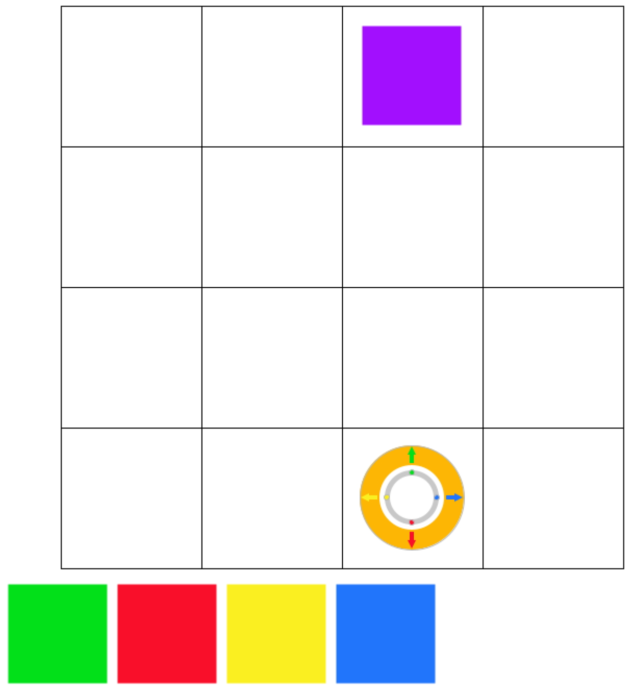


Figure 10: *Screenshot of an Android application simulating programming activity with Robotito.*

the opposite team by choosing the color card to put the robot on, as the orientation of the robot was defined by the researcher and could not be changed (see Figure 9).

Then we discovered a new card—a purple card that makes the robot turn all the lights purple and spin on the spot. This card was used as a destination card in the second part of the activity. The purple card was placed next to the opposite team and color cards were placed in front of the team that was handling Robotito. The child that was on task had to reach the purple card by rotating the robot and putting it in the correct place on the mat (see Figure 9). Each child did both—chose the color card and rotated the robot.

In the final part of the session we proposed a more open-ended activity in which the children were sitting in a circle and one child was putting color cards in the robot's path to prevent it from leaving the circle (see Figure 9). After the child selected the color of the card and put it in the robot's trajectory, the color cards were passed to the next child.

Activity #4 Total time: 40 minutes. In this activity the children interacted with an Android application that was simulating Robotito, 4 x 4 mat and color cards (see Figure 10). We first explained the app on TV to the whole group and solved together with children some example tasks. The children worked in pairs changing the person

Figure 11: *Children observing the robot's behavior after passing over the orange card.*

that is in charge of programming on the tablet. The programmer had to choose color cards to guide the robot to the purple card. Once reached the purple card, the child drew a smiling face on the A4 paper sheet to mark that the task was fulfilled and passed the tablet to its partner that proceeded with the next task.

Activity #5 Total time: 40 minutes. The class was divided into two groups. The first group worked in pairs on on-paper tasks in which the children had to paint already fixed coding card with the the right colors to make the robot reach the purple card, or define the place and the color of the cards that direct the robot to the purple card and draw them on the paper grid (see Appendix F).

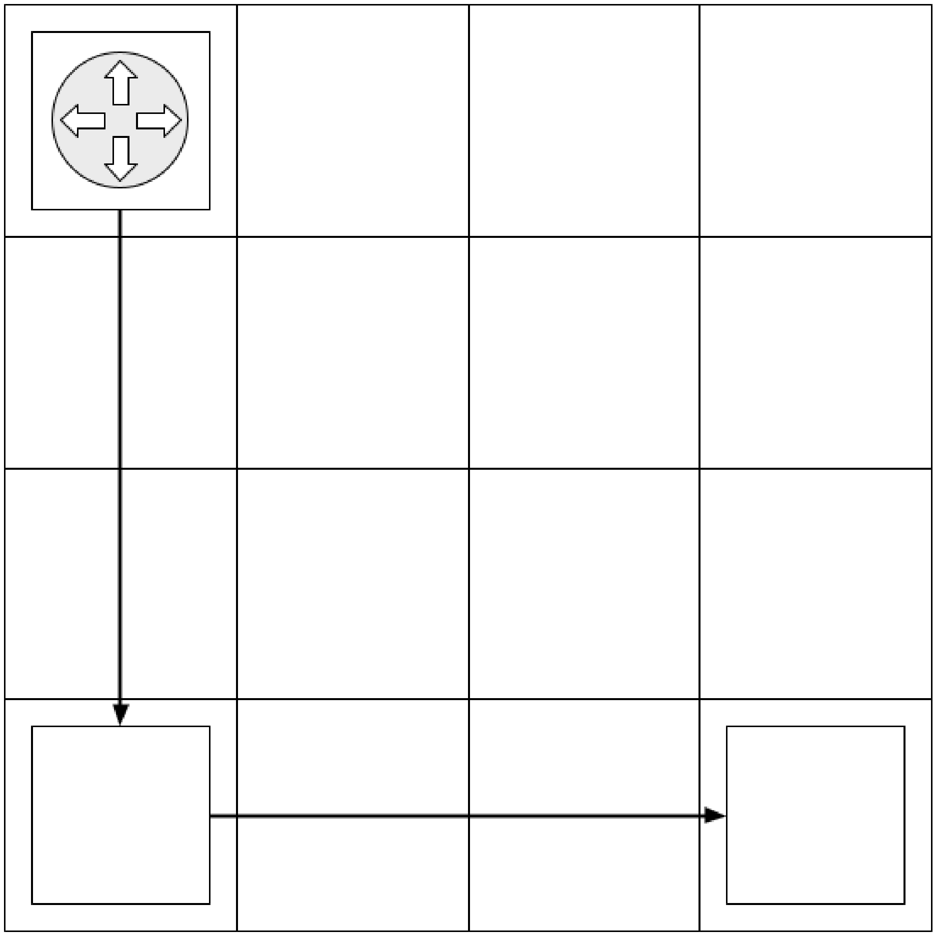
The second group prepared a square-shaped path that was used to introduce the new orange card. We imagined what the card would do, and then introduced it to the prepared path and observed how the robot responded to it (see Figure 11). The children were invited to reflect how to activate and deactivate the sound reproduction and to propose routes that integrate an orange card.

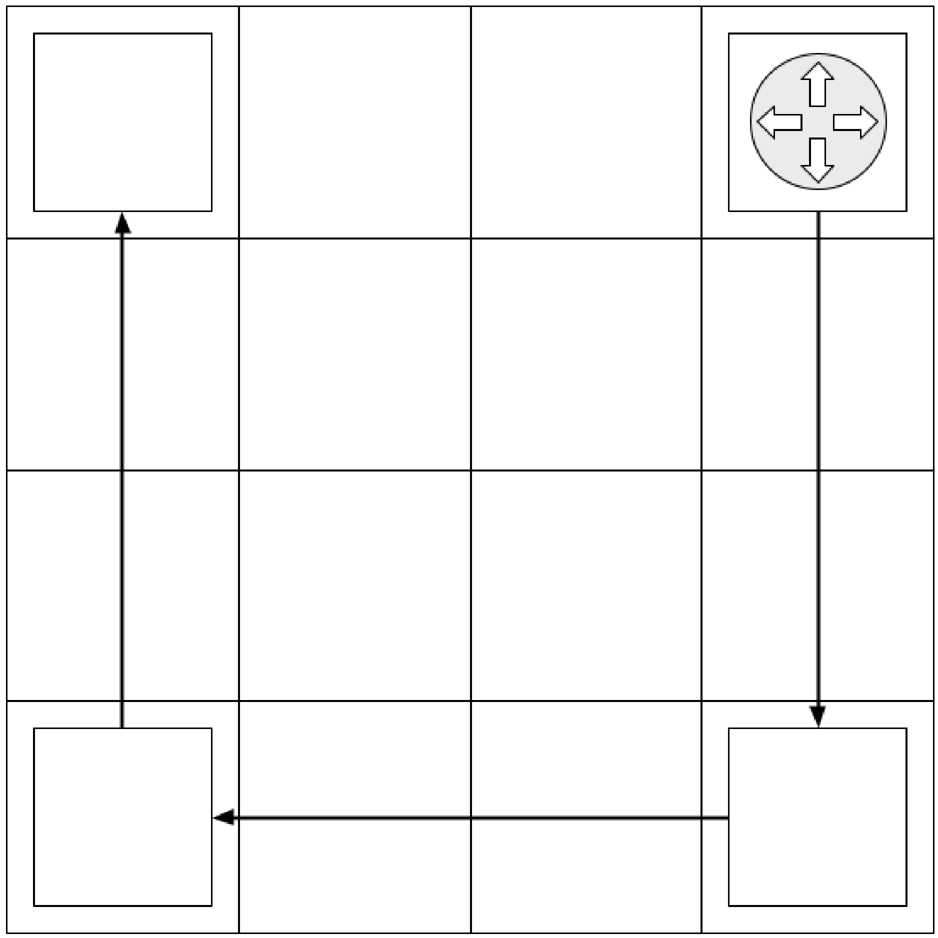
Activity #6 Total time: 60 minutes (10 minutes per group). We formed small groups (1 to 3 children) and each group worked with Robotito for about 10 minutes, while the rest of the class performed curricular activities with the teacher. The children in the small group were distributed around the 4 x 4 mat. Each child was invited to code with color cards a L-shaped path from a point next to it to one of the classmates or to the researcher. The initial orientation of the robot, the initial position, and the end point were defined by the researcher. In some cases, to make the task more challenging, we used white cards with an X in the middle that indicated that the robot should not pass through that cell. In other cases we asked the child to prepare the path and activate the music before arriving at the end point. All the group members participated in the final task in which they programmed a long path that incorporated music activation and deactivation.

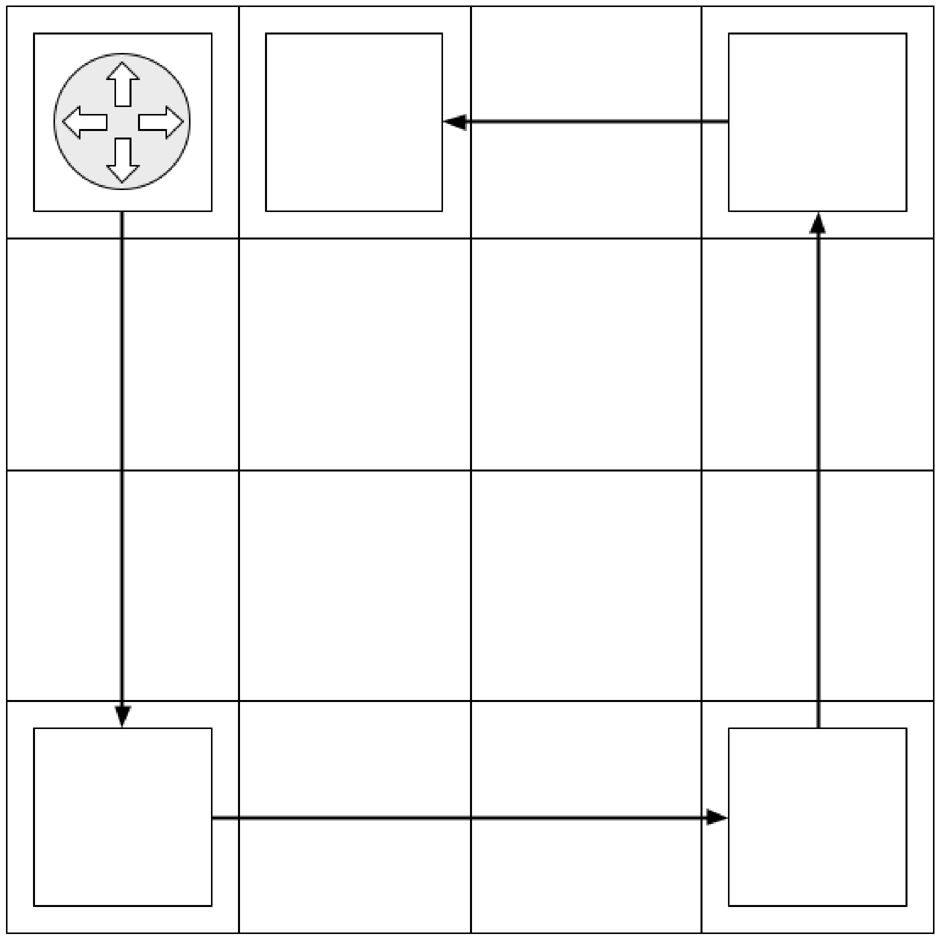
Activity #7 Total time: 30 minutes. The class was divided into two groups and each group worked with one researcher on the same task. First we introduced the pink coding card and thought how Robotito responds to it. After turning on the robot and observing how it acts. The researcher rotated the robot and each child tried to predict in which cell it would stop after sensing the pink card. We ended the session with building paths suggested by the children.

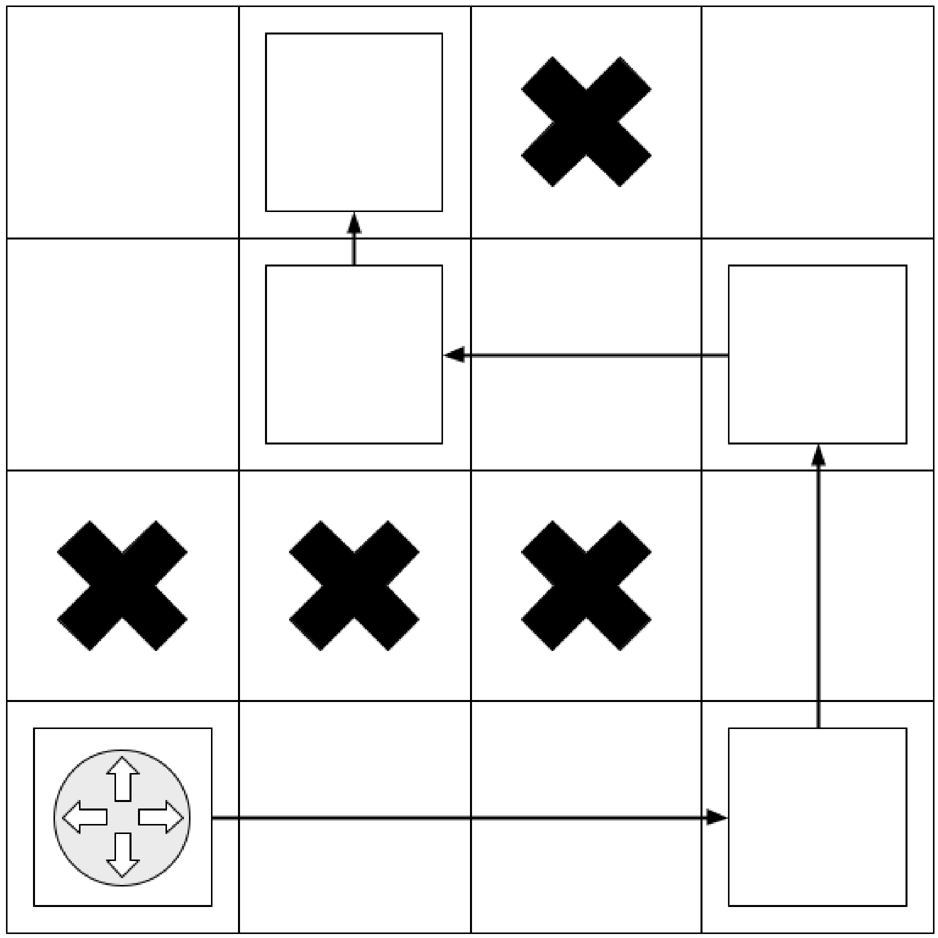
Activity #8 Total time: 75 minutes (10 to 15 per group). We formed small groups (1 to 3 children) and each group worked with Robotito for about 10 to 15 minutes, while the rest of the class performed curricular activities with the teacher. Each child had to solve a task based on combining the pink card (initial point) with other color cards to reach the purple card. In those exercises the rotation of the robot was fixed by the researcher. In the final exercise the children had to predict what happens when we build a diagonal with three pink cards that crosses the mat and end with the purple card.

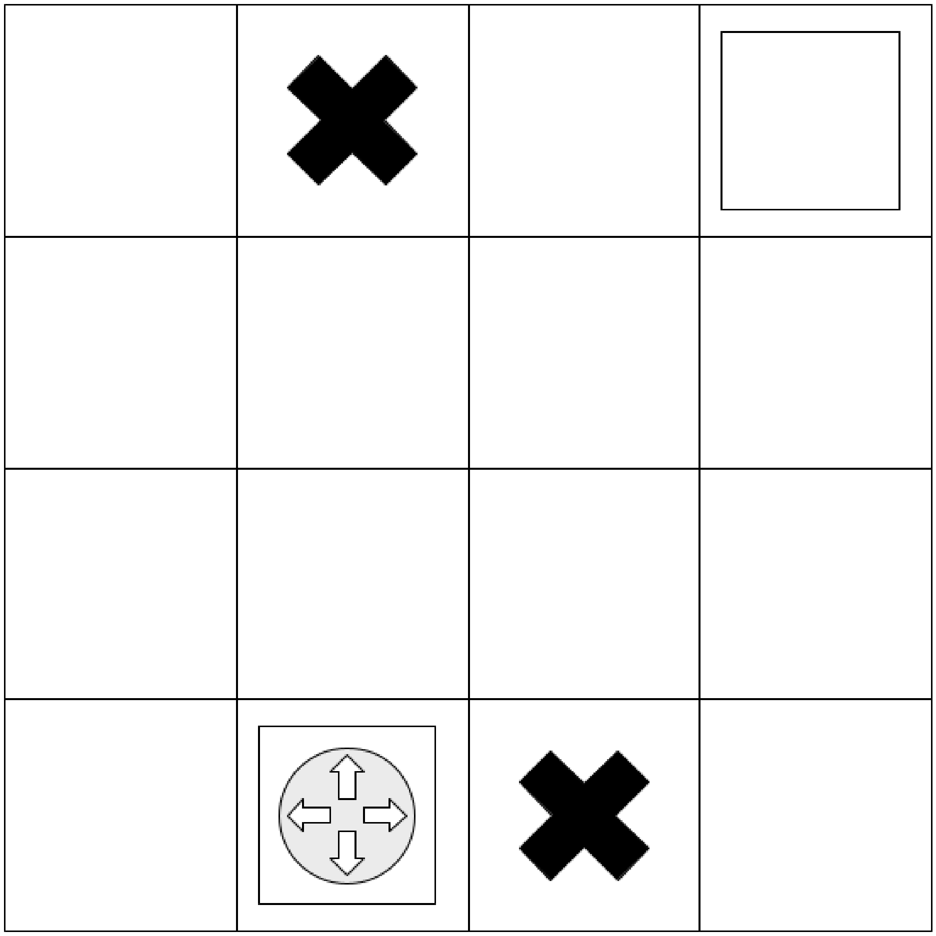
F On-paper tasks for activity #5

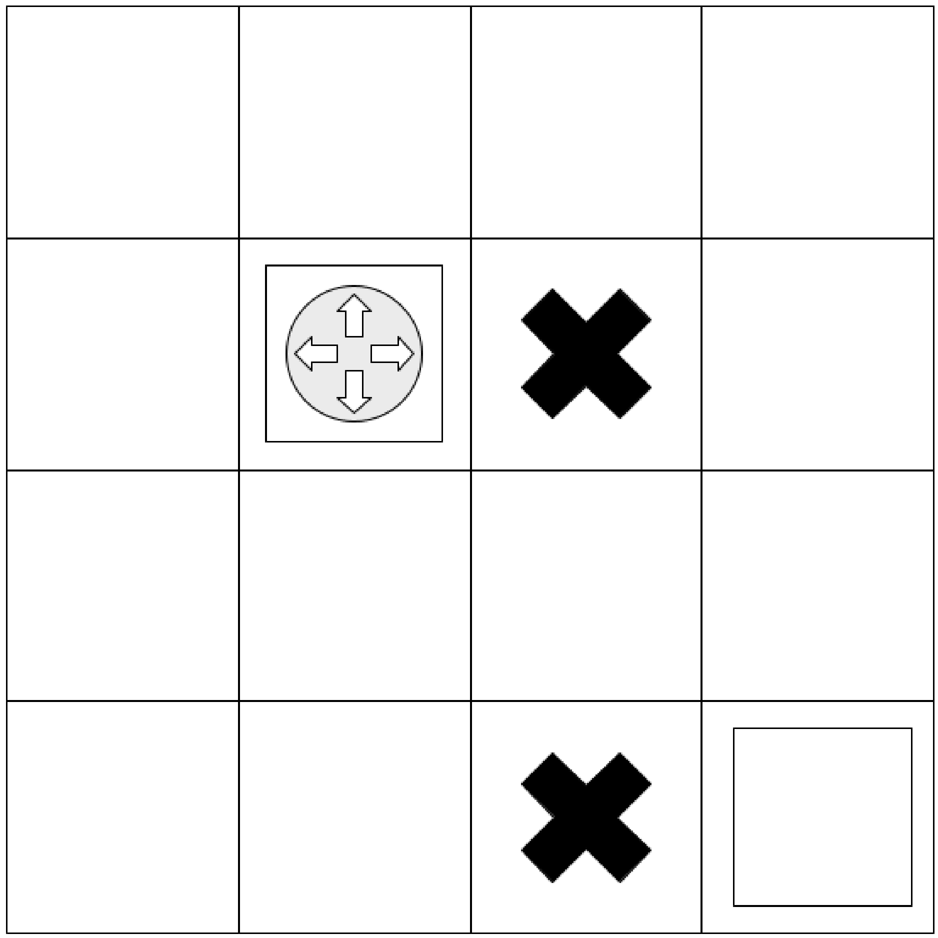


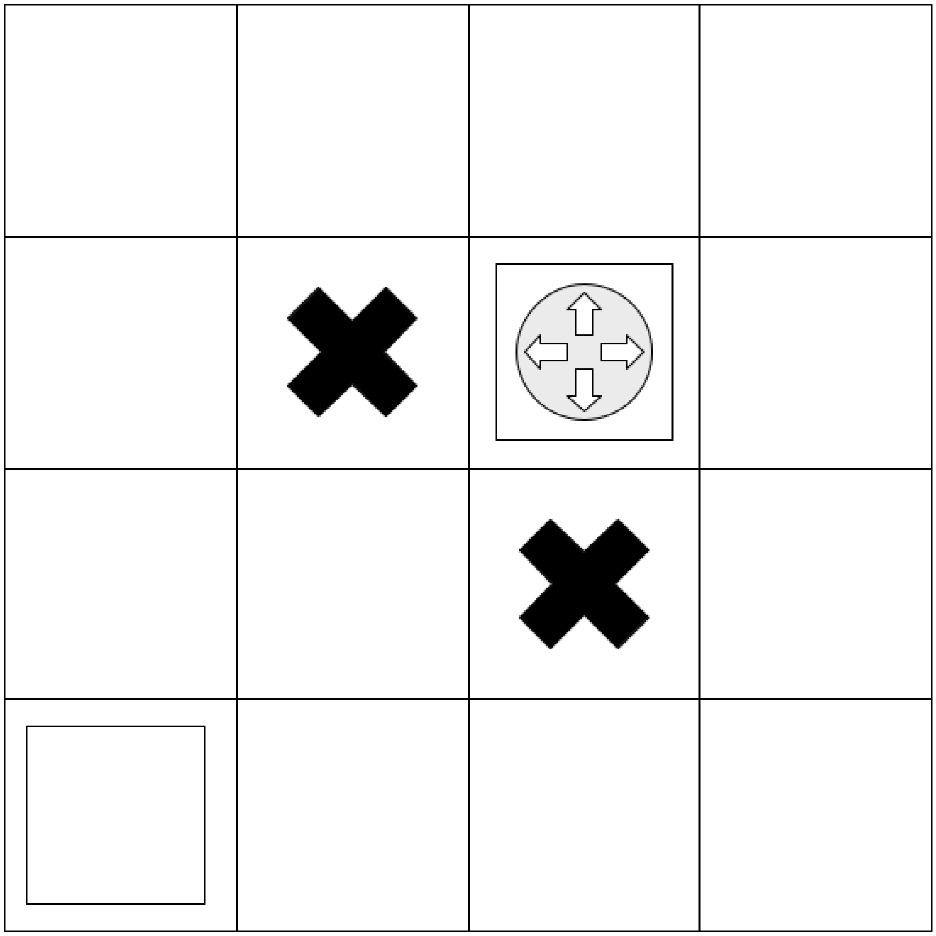












G BCTt results

ID	TYPE	GROUP	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
A2-1	PRE	A2	1	1	0	0	0	0	0	0	0	1	0	1	1
A2-2	PRE	A2	0	0	0	0	0	0	1	0	0	1	0	1	0
A2-3	PRE	A2	1	1	0	0	0	1	1	0	0	0	1	0	1
A2-4	PRE	A2	1	1	1	0	0	1	1	0	1	0	0	0	1
A2-5	PRE	A2	0	1	1	1	1	1	1	0	0	1	0	0	0
A2-6	PRE	A2	0	0	0	0	0	0	0	1	0	1	0	0	1
A2-7	PRE	A2	0	1	1	1	0	0	1	0	1	1	1	0	1
A2-8	PRE	A2	0	0	1	1	1	0	1	0	0	1	0	0	1
A2-9	PRE	A2	0	0	1	0	0	1	1	1	1	0	0	0	1
A2-10	PRE	A2	1	1	1	1	1	1	1	1	1	1	1	0	1
A2-11	PRE	A2	0	0	1	0	0	1	1	0	1	1	0	0	0
A2-12	PRE	A2	1	0	1	1	1	1	0	1	0	1	0	0	1
A2-13	PRE	A2	1	1	0	1	1	0	0	0	0	1	0	0	1
A2-14	PRE	A2	1	0	0	0	0	0	0	0	1	0	0	0	1
A2-15	PRE	A2	0	1	0	1	0	0	0	0	0	0	0	0	0
A2-16	PRE	A2	1	1	1	0	1	1	1	1	1	0	0	0	1
A2-17	PRE	A2	1	1	1	1	1	1	0	1	0	1	1	1	1
A2-18	PRE	A2	1	1	1	1	1	1	1	1	1	1	1	1	1
A2-19	PRE	A2	1	1	1	1	1	1	0	0	1	0	0	0	0
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A1-2	PRE	A1	1	0	1	0	0	1	0	0	0	1	0	1	0
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A1-5	PRE	A1	1	0	0	0	0	1	0	0	0	0	0	0	0
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A1-7	PRE	A1	0	0	1	1	1	0	0	0	0	1	0	0	0
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A1-9	PRE	A1	0	1	1	1	0	1	0	1	1	1	1	0	1
A1-10	PRE	A1	1	0	1	1	0	0	1	0	0	1	0	0	1
A1-11	PRE	A1	1	1	1	1	1	0	1	1	1	0	0	1	1
A1-12	PRE	A1	1	0	1	1	1	0	1	1	1	1	0	0	1
A1-13	PRE	A1	0	0	0	1	0	1	1	0	0	1	0	0	1
A1-14	PRE	A1	0	1	1	0	1	0	1	0	0	1	0	0	1
A1-15	PRE	A1	1	1	1	1	0	1	1	0	0	1	0	1	1
A1-16	PRE	A1	0	1	1	1	1	0	0	0	0	0	1	1	0
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CG-1	PRE	CG	0	1	1	1	1	1	0	0	0	0	1	0	1
CG-2	PRE	CG	1	0	0	0	1	0	1	0	1	0	0	1	0
CG-3	PRE	CG	0	1	1	1	0	1	0	0	0	1	0	0	1
CG-4	PRE	CG	1	1	1	1	1	1	0	0	1	1	0	0	1
CG-5	PRE	CG	1	0	1	0	0	0	0	1	0	1	0	0	0
CG-6	PRE	CG	1	1	1	0	1	1	1	0	0	1	0	0	1
CG-7	PRE	CG	1	1	1	1	0	1	1	0	1	1	0	1	1
CG-8	PRE	CG	1	1	1	1	1	1	0	0	0	1	0	0	0
CG-9	PRE	CG	1	1	1	1	1	1	0	0	1	1	0	0	1
CG-10	PRE	CG	0	1	1	1	0	0	0	0	1	1	0	0	1
CG-11	PRE	CG	0	1	0	0	1	0	1	1	1	0	0	0	1
CG-12	PRE	CG	0	0	1	1	1	1	0	0	1	1	0	0	0
CG-13	PRE	CG	1	0	0	0	0	0	0	0	0	0	0	1	1
CG-14	PRE	CG	1	1	1	1	0	1	1	0	1	0	0	0	1
CG-15	PRE	CG	1	1	0	1	1	0	1	1	1	1	1	1	1
CG-16	PRE	CG	1	1	1	1	1	1	1	1	1	1	1	0	1
CG-17	PRE	CG	1	1	1	0	0	1	0	1	1	1	1	1	1
CG-18	PRE	CG	1	0	1	1	1	1	1	0	0	1	1	1	1
CG-19	PRE	CG	0	1	1	0	0	1	1	0	1	1	1	0	1
CG-20	PRE	CG	1	1	1	1	1	1	0	0	1	1	1	0	1
A2-1	POST	A2	1	1	1	1	1	0	0	0	1	1	0	0	1
A2-2	POST	A2	1	1	0	1	0	0	1	0	0	0	1	0	1
A2-3	POST	A2	0	0	1	1	0	0	0	0	0	0	0	0	0
A2-4	POST	A2	1	1	1	1	1	1	1	0	0	1	1	0	1
A2-5	POST	A2	1	1	1	1	1	1	1	0	0	1	0	1	1
A2-6	POST	A2	1	1	1	0	0	1	0	0	0	1	0	1	0
A2-7	POST	A2	1	1	1	1	1	1	1	1	1	1	0	1	1
A2-8	POST	A2	1	1	1	1	1	1	1	1	1	1	1	1	1
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A2-10	POST	A2	1	1	1	1	1	1	1	1	1	0	1	0	1
A2-11	POST	A2	1	1	1	1	1	1	1	0	1	1	1	0	1
A2-12	POST	A2	0	1	1	0	0	0	1	1	0	1	0	0	0
A2-13	POST	A2	1	1	1	0	0	0	1	0	1	0	1	0	0
A2-14	POST	A2	1	1	0	0	0	0	1	0	1	0	0	0	1
A2-15	POST	A2	0	1	0	0	0	0	0	0	1	0	0	1	0
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A2-19	POST	A2	1	1	1	1	1	1	1	0	1	1	0	0	1
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A1-8	POST	A1	0	0	0	0	0	0	1	0	1	0	1	1	1
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A1-11	POST	A1	1	1	1	1	1	1	0	0	1	0	0	1	0
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A1-13	POST	A1	1	1	0	0	1	0	0	0	0	0	1	0	1
A1-14	POST	A1	1	1	1	1	0	0	0	0	1	1	0	0	1
A1-15	POST	A1	1	1	1	1	1	1	1	0	0	1	0	0	1
A1-16	POST	A1	0	1	0	1	0	1	0	0	1	1	0	0	1
A1-17	POST	A1	1	0	1	0	0	0	1	0	1	1	1	0	0
CG-1	POST	CG	1	0	0	0	1	0	1	0	1	0	1	0	1
CG-2	POST	CG	0	0	0	0	1	1	1	0	1	0	1	0	1
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CG-12	POST	CG	1	1	1	1	1	0	1	0	1	0	0	0	0
CG-13	POST	CG	0	0	1	1	0	1	0	0	0	0	0	1	0
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CG-15	POST	CG	1	1	1	1	1	1	1	0	1	0	0	1	1
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CG-18	POST	CG	1	1	1	1	1	0	1	0	0	0	1	1	1
CG-19	POST	CG	1	1	1	1	1	1	1	0	1	1	1	0	1
CG-20	POST	CG	1	1	1	1	1	1	1	0	1	1	1	0	1

H TechCheck-K results

ID	TYPE	GROUP	P1	P2	P3	P4	P5	P6	P7	P8	P9
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A2-2	PRE	A2	1	0	0	1	0	0	0	1	1
A2-3	PRE	A2	0	0	0	1	1	1	0	1	0
A2-4	PRE	A2	0	1	1	0	1	0	1	1	1
A2-5	PRE	A2	0	1	0	0	0	0	0	1	1
A2-6	PRE	A2	1	1	1	0	0	0	0	1	1
A2-7	PRE	A2	1	1	1	0	0	0	1	1	1
A2-8	PRE	A2	1	0	1	1	0	0	0	1	1
A2-9	PRE	A2	0	1	1	1	0	1	1	1	1
A2-10	PRE	A2	1	0	0	1	0	0	1	1	1
A2-11	PRE	A2	1	0	1	1	0	0	0	1	1
A2-12	PRE	A2	0	0	0	1	0	0	1	1	1
A2-13	PRE	A2	0	1	0	1	0	1	0	1	0
A2-14	PRE	A2	0	1	1	0	1	1	0	0	1
A2-15	PRE	A2	1	0	1	0	0	0	0	0	0
A2-16	PRE	A2	0	1	1	1	0	0	0	1	1
A2-17	PRE	A2	1	1	0	0	0	0	1	1	1
A2-18	PRE	A2	1	1	1	0	0	1	0	1	0
A2-19	PRE	A2	1	1	0	1	1	0	0	1	1
A1-1	PRE	A1	0	1	1	0	0	0	0	0	1
A1-2	PRE	A1	1	1	1	0	1	1	0	1	1
A1-3	PRE	A1	0	0	0	1	0	0	0	1	1
A1-4	PRE	A1	1	1	0	0	0	0	1	1	1
A1-5	PRE	A1	1	1	1	0	0	1	0	1	1
A1-6	PRE	A1	0	1	0	1	0	0	0	0	0
A1-7	PRE	A1	1	1	0	0	1	0	0	1	1
A1-8	PRE	A1	1	1	1	1	0	0	1	1	1
A1-9	PRE	A1	0	1	0	0	1	0	1	1	1
A1-10	PRE	A1	1	1	0	1	0	1	1	1	1
A1-11	PRE	A1	0	1	1	0	1	0	0	1	1
A1-12	PRE	A1	0	1	1	0	1	0	0	0	0
A1-13	PRE	A1	0	0	1	0	0	0	1	0	0
A1-14	PRE	A1	0	1	1	0	0	0	1	1	0
A1-15	PRE	A1	0	1	1	0	0	0	1	1	1
A1-16	PRE	A1	0	0	0	1	0	1	0	1	0
A1-17	PRE	A1	1	1	0	0	0	1	0	0	0
CG-1	PRE	CG	0	1	1	0	0	0	0	1	1
CG-2	PRE	CG	1	0	0	0	1	0	0	0	1
CG-3	PRE	CG	0	0	1	1	1	0	0	1	0
CG-4	PRE	CG	0	1	0	0	1	0	1	1	1
CG-5	PRE	CG	0	0	1	0	0	0	1	1	0
CG-6	PRE	CG	0	1	0	0	0	0	1	1	1
CG-7	PRE	CG	1	1	1	0	0	0	0	1	1
CG-8	PRE	CG	1	1	1	1	0	0	1	1	0
CG-9	PRE	CG	0	1	0	1	0	0	0	1	1
CG-10	PRE	CG	1	0	0	1	0	1	0	1	1
CG-11	PRE	CG	0	1	1	0	0	0	1	1	0
CG-12	PRE	CG	1	1	1	0	0	0	0	1	1
CG-13	PRE	CG	0	0	1	0	0	0	1	0	1
CG-14	PRE	CG	1	1	1	0	1	0	1	1	0
CG-15	PRE	CG	1	1	1	0	0	1	1	1	1
CG-16	PRE	CG	0	1	1	0	0	0	0	1	1
CG-17	PRE	CG	1	0	0	1	0	1	1	1	1
CG-18	PRE	CG	1	1	1	1	0	1	1	1	1
CG-19	PRE	CG	0	0	0	0	0	0	0	1	1
CG-20	PRE	CG	1	1	0	0	1	0	0	1	1
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A2-3	POST	A2	1	0	0	0	0	0	0	1	1
A2-4	POST	A2	1	1	0	1	0	0	0	1	1
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A2-11	POST	A2	1	0	1	0	0	0	1	1	1
A2-12	POST	A2	1	1	0	0	0	1	0	1	1
A2-13	POST	A2	0	1	1	0	0	0	0	1	1
A2-14	POST	A2	1	1	1	0	1	0	0	1	1
A2-15	POST	A2	1	0	0	0	0	1	0	0	0
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A2-17	POST	A2	1	1	0	1	0	0	1	1	1
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A2-19	POST	A2	1	1	1	1	1	0	0	1	1
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A1-4	POST	A1	1	1	1	0	0	1	1	1	1
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A1-7	POST	A1	0	1	1	0	0	0	0	1	0
A1-8	POST	A1	1	1	0	1	0	0	0	1	1
A1-9	POST	A1	1	1	1	0	0	0	0	0	0
A1-10	POST	A1	0	1	1	1	0	0	0	1	1
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A1-12	POST	A1	1	1	0	1	0	0	1	1	1
A1-13	POST	A1	0	1	1	0	1	0	0	1	1
A1-14	POST	A1	1	1	1	0	0	0	0	1	1
A1-15	POST	A1	1	1	1	1	1	1	0	1	1
A1-16	POST	A1	1	1	1	0	0	0	0	1	1
A1-17	POST	A1	0	1	1	1	0	1	0	1	1
CG-1	POST	CG	0	0	0	0	0	0	0	1	1
CG-2	POST	CG	0	0	1	0	0	0	0	1	1
CG-3	POST	CG	1	0	1	0	1	1	0	1	1
CG-4	POST	CG	1	1	1	1	1	1	0	1	1
CG-5	POST	CG	0	0	0	0	0	0	0	1	0
CG-6	POST	CG	1	1	1	0	0	0	0	1	1
CG-7	POST	CG	0	0	0	1	1	0	1	1	1
CG-8	POST	CG	1	1	1	1	1	0	0	1	1
CG-9	POST	CG	0	1	0	1	0	1	1	1	1
CG-10	POST	CG	1	0	0	1	0	0	0	1	1
CG-11	POST	CG	0	1	1	0	0	0	0	1	1
CG-12	POST	CG	1	1	1	0	0	0	0	1	1
CG-13	POST	CG	0	1	1	0	0	1	0	1	1
CG-14	POST	CG	1	1	1	1	1	1	1	1	1
CG-15	POST	CG	0	1	1	1	0	1	0	0	1
CG-16	POST	CG	1	0	1	1	0	0	1	1	1
CG-17	POST	CG	1	0	1	1	1	0	1	1	1
CG-18	POST	CG	0	0	0	1	0	0	0	1	1
CG-19	POST	CG	0	0	1	0	0	1	0	1	1
CG-20	POST	CG	1	1	0	0	1	0	0	1	1

I Robotito Test results

ID	GROUP	P1	P2	P3	P4
A2-1	A2	1	1	1	1
A2-2	A2	1	1	0	1
A2-3	A2	1	0	0	1
A2-4	A2	1	1	1	1
A2-5	A2	1	1	0	1
A2-6	A2	1	0	1	1
A2-7	A2	1	1	1	1
A2-8	A2	1	1	0	1
A2-9	A2	1	1	1	0
A2-10	A2	1	1	1	1
A2-11	A2	1	1	1	1
A2-12	A2	1	1	0	0
A2-13	A2	1	1	0	0
A2-14	A2	1	0	0	0
A2-15	A2	1	0	0	0
A2-16	A2	1	1	0	1
A2-17	A2	1	1	1	1
A2-18	A2	1	1	1	1
A2-19	A2	1	1	0	1
A1-1	A1	1	1	0	1
A1-2	A1	1	0	0	0
A1-3	A1	1	1	1	1
A1-4	A1	1	1	1	1
A1-5	A1	1	1	1	1
A1-6	A1	1	1	1	0
A1-7	A1	1	1	1	1
A1-8	A1	1	0	1	0
A1-9	A1	1	1	1	0
A1-10	A1	1	1	0	0
A1-11	A1	1	1	1	1
A1-12	A1	1	1	0	0
A1-13	A1	1	0	0	0
A1-14	A1	1	1	0	1
A1-15	A1	1	1	1	1
A1-16	A1	1	0	1	0
A1-17	A1	1	1	1	0