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The impact of an educational robot-based intervention on second-graders computational thinking skills: The experimental evaluation of the *Irûmi* program in Paraguay*

Emma Näslund-Hadley, Juan Manuel Hernández-Agramonte, Humberto Santos, and Pablo Zoido

Abstract

In this article, we present the impact evaluation of Irûmi, an educational robot-based intervention aimed at developing second-grade students' computational thinking (CT) skills in Paraguay. Our results indicate that the program had an effect of 0.09 standard deviations on the students' CT skills, focusing on abilities such as abstraction, algorithmic thinking, and evaluation. These findings suggest that with age-appropriate instructional design, very young children could develop CT skills and, that smart devices and electronic toys can contribute to their development at early ages. Several mechanisms may explain these results. First, Irûmi increased the likelihood that teachers would use educational technology in the classroom, including devices not explicitly provided by the program. Second, the program contributed to the development of teachers' CT skills, possibly due to the novelty of the curriculum and methodology in the Paraguayan context. Third, Irûmi may have increased teachers' motivation to use technology, thereby strengthening their positive attitudes toward its integration into teaching. Beyond its effects on CT skills, Irûmi generated additional benefits for students. In particular, it increased preferences for science, technology, engineering, and mathematics (STEM)-related toys and promoted greater gender flexibility regarding who can play with them, especially among girls. It also improved boys' and girls' attitudes toward technology. Our study contributes to the empirical literature by focusing on a middle-income country, using an experimental design with pre- and post-intervention measures, working with a large sample of students, and analyzing the impact on both students and teachers.

Keywords: computational thinking; early childhood education; educational robots; randomized controlled trial (RCT); Paraguay

JEL Codes: C93, I20, I24

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1. Introduction

Computational Thinking (CT) is the term in current use to refer to the key ideas and concepts of the disciplinary areas of Informatics and Computer Science. In the past decade this topic has been gaining increasing attention from researchers, practitioners, and policy makers in the education field worldwide (Bocconi et al., 2016; Bakala et al., 2021).

Despite the widespread use of the term CT, there is still debate about its exact definition. However, in several investigations the definition in Wing (2011) is taken as a starting point. Wing (2011) defines CT as: "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent". From this definition, two fundamental elements emerge that characterize CT and that are relevant to the discussion in education. First, CT is a type of thinking process that can be independent of the use of technology, and second, CT is a type of problem-solving process involving specific skills and whose solutions can be presented in a form that could be conducted by a computer or other information-processing agent.

Regarding the first element, there is consensus that CT is a set of transversal skills that go beyond computer use and programming and therefore is not restricted only to computer scientists (Quiroz-Vallejo et al., 2021; Voogt et al., 2015; Wing, 2006). In this sense CT would be an analytical skill (as relevant as reading, writing and arithmetic) that facilitates communication and interaction with others (Wing, 2008) and the development of daily life activities (Tang et al., 2022). That is why many governments have included CT in the school curricula as a key 21st century skill for schoolchildren (Bati, 2022; Bocconi et al., 2016).

Regarding the second element, various authors define different concepts and skills associated with CT. Bocconi et al (2016), based on a review of studies widely cited in the literature (Angeli et al., 2016; Barr & Stephenson, 2011; Grover & Pea, 2013; Lee et al., 2011; Selby & Woollard, 2013), define the following CT core skills:

- *Abstraction:* the process of making an artefact more understandable through reducing unnecessary details.
- *Algorithmic thinking:* a way of getting to a solution through a clear definition of the steps.
- *Automation:* a labor-saving process in which a computer is instructed to execute a set of repetitive tasks quickly and efficiently compared to the processing power of a human.
- *Decomposition:* a way of thinking about artefacts in terms of their component parts. The parts can then be understood, solved, developed, and evaluated separately.

- *Debugging:* the systematic application of analysis and evaluation to find and correct bugs and errors.
- *Generalization:* associated with identifying patterns, similarities, and connections, and exploiting those features. It is a way of quickly solving new problems based on previous solutions and building on prior experience.

The increased importance of CT in the policy debate in education, and in early childhood education (ECE) in particular stems from four factors. First, because there is evidence that CT learning has effects on other important skills relevant for using Information and Communication Technologies (ICT) at a young age, for example, critical thinking, communication, collaboration, and creativity skills (Bers et al., 2019; Critten et al., 2022) and self-regulation (Yang et al., 2022). Second, because the integration of CT and programming activities in ECE can allow children to discover and understand the technologies that they encounter in their everyday lives (Sullivan & Bers, 2016). Third, some authors argue that early childhood is a critical period for the development of CT because children are in a transitional stage between concrete and abstract mental processes (Flannery & Bers, 2013). Fourth, several recent investigations conclude that interventions in early childhood have a higher rate of return than interventions at later stages and long-term impact on economic, health, and social outcomes (e.g. García et al., 2020).

Given the relative consensus on the importance of CT, one question is whether systematic interventions can develop these skills in early childhood. Several studies have reviewed the empirical evidence about how various educational interventions might enhance CT at this stage (Bakala et al., 2021; Bati, 2022; Quiroz-Vallejo et al., 2021; Su & Yang, 2023). In general, these studies agree that: i) with age-appropriate instructional design, young children could develop early concepts and skills of CT; ii) smart devices and electronic toys (e.g. robots) can contribute to the development of programming and CT skills in ECE; iii) despite the understanding of the importance of teaching CT, there is still little evidence on what practices are most effective for developing children's CT skills in ECE; iv) among the available evidence there is a lack of studies for low and middle income countries, there are few evaluations with experimental design, the samples of students used in the evaluations are in general small and most of them do not address some relevant topics such as the impact of gender and socioeconomic status on CT learning or the role of adults (e.g. teachers) in the development of the activities.

To contribute to this literature, in this article we present the results of the impact evaluation of *Irûmi*[1], an educational program aimed to develop CT skills in second-grade students of public primary education in Paraguay. *Irûmi* was developed jointly by the Multidisciplinary Organization to Support Teachers and Students

[1] *Irûmi* is a word from the Guaraní language that means companion.

(*Organización Multidisciplinaria de Apoyo a Profesores y Alumnos* OMAPA[2]), the Ministry of Education and Sciences of Paraguay (MEC), and the Inter-American Development Bank (IDB). The educational proposal included a study plan of 18 topics associated with activities to be developed in the classroom and a technological educational kit (including a robot) with which some of the activities proposed in the study plan were carried out. The robots were developed and donated by the company SK Telecom[3], which in collaboration with the Teacher's Association of Primary Computer Education in Korea, adapted the materials for the program. In addition to the study plan and materials the program also included teacher support strategies such as training and visits from tutors. The intervention was implemented in 104 schools distributed in 7 departments of Paraguay during a period of approximately 11 weeks (from August 15 to October 29, 2022). To evaluate *Irûmi* we used an experimental impact evaluation (Randomized Controlled Trial - RCT) design with a sample of 207 schools (104 in the treatment group and 103 in the control group), 2040 students and 160 teachers.

The structure of the article is as follows. In Section 2, following this introduction, we describe the components of the Irûmi program. In Section 3 we discuss the expected outcomes of the program, and the measurement instruments and outcome variables considered in the evaluation. In Section 4 we present the experimental design of the evaluation. In Section 5 we describe the sample characteristics and the balance between the treatment and control groups. In Section 6 we present the main effects of the program on students and teachers. Finally, in Section 6 we discuss the relevance of our results for academic and education policy discussions.

2. The *Irûmi* Program

This section describes the content and development of the *Irûmi* program, an educational program aimed to develop CT skills in second-grade students of public primary education in Paraguay. The educational proposal includes a study plan of 18 topics that propose activities to be developed in the classroom and a technological educational kit with which the activities proposed in the study plan are carried out. In addition to the study plan and materials the program also included teacher support strategies such as visits from tutors and training.

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[2] OMAPA is a non-profit mathematical organization founded more than 20 years ago, based in Asunción (Paraguay). More information about OMAPA in https://www.omapa.org/
[3] SK Telecom is a South Korean company, specialized in the manufacturing of mobile phones and telecommunications services. More information about SK Telecom in https://www.sktelecom.com/index_en.html

2.1. Curriculum

The Irûmi curriculum (see Table A1 in the Appendix), developed in the teacher guidebook and student workbooks, was designed by teachers from the Teacher's Association of Primary Computer Education in Korea, who are experts in coding education. Each topic in the curriculum develops a programming activity, which allows students to learn basic concepts of CT through solving different problems. During the activities, students arrive at a solution by determining a sequence of instructions that the robot is expected to perform. Subsequently, thanks to the sensors that the robot has on the base, the student scans the sequence of coded cards to execute them on the navigation board. The details of the planned activities are as follows:

The first activities of the curriculum, called "Disconnected Activities", aim to introduce programming concepts without using the robot or programming cards and are included between topics 1 to 4:

Topic 1: Move! Let's be a robot. In this lesson one of the students assumes the role of a robot and the rest of the students assume the role of programmers. The programmers instruct the student who plays the role of the robot to move on a map that has been created by the teacher together with the students and that has been placed on the floor. Programmers choose the direction in which the student-robot will move, using large cards with different prompts, such as "Go forward for 1 second," "Go back for 1 second," "Turn right for 1 second," "Turn left for 1 second", "Run program" (execute the commands), "Delete program" (discard the commands), "Stop program (stop the commands), "Repeat 2 times", "Repeat 3 times" and "End repetition". Once the student assuming the robot role reaches their destination, the roles change, and the players begin playing again. If the student-robot does not reach its destination, the students must find out which order was incorrect and correct it.

Topic 2: Move! Capture of dolls. In this activity, objects such as "dolls" are placed on a map placed on the ground. Continuing with the dynamics of the previous activity, the students participate in a role-play, in which one is the robot, and the other is the programmer. The programmer gives orders to the student who plays the role of the robot, using cards from the previous activity, as well as an additional card called "Say". The programmer orders the student-robot to capture the doll and then return to its original location with the doll.

Topic 3: Move! Land conquest game. In this activity, one of the students assumes the role of a programmer and another the role of a land-conquering robot, who, to conquer an area, must place a card of the color of his team. The student programmer must make the student-robot move to the places he plans to conquer and then, using the "Say" card, order him to leave a colored card when he reaches the area. The robot cannot place a colored card in a place where another team has already placed its card.

Topic 4: Move! Box construction game. In this activity, the programmer and robot role-playing game continues, but in this case the objective is to stack a group of boxes following certain shapes indicated by the teacher. The game has rules that the student-programmer must consider when he programs the commands. Using a new card called “Beep” (sound) the programmer orders and notifies the start of the game. Subsequently, he begins to create the sequence of orders for the other members of his team who assume the role of robots, using the large cards. When the programmer says “Play”, using the “Say” card, the team members must follow the created orders. Once the student-robots reach the indicated positions, using the “Say” card, the student-robots are ordered to grab the boxes, stack them according to the shapes indicated by the teacher and finally return to their initial position.

Topics 5 to 9 (“Familiarization Activities”) seek to familiarize the student with the technological components of the educational kit:

Topic 5: Say hello to your robot friend! This activity aims to understand the parts and operation of the *Irûmi* robot and the coding cards.

Topic 6: Say hello to your robot friend! This lesson has the objective that through a hide and seek game the student finds solutions and subsequently determines the instructions that the *Irûmi* robot must follow to reach that solution.

Topic 7: Playing to eat candies. In this lesson a game is proposed where the robot *Irûmi* must manage to collect the candies that are scattered on the navigation boards. This activity addresses concepts of problem solving and debugging.

Topic 8: Who is good at this? The activity proposes that two teams play penalty kicks using the boards and coding cards. To do this, students must identify the position of the goal and the ball and, through instructions to the robot, manage to reach the opposing team's goal. This activity addresses concepts of problem solving, repetition, and debugging.

Topic 9: Draw! In this activity, students are asked to place a marker on the *Irûmi* robot, so that following instructions the robot makes strokes emulating drawings proposed by the teacher.

Between topics 10 to 18 “Reinforcement and new topics” different activities are proposed that seek on the one hand, to reinforce the learned concepts of sequence, repetition and debugging and, on the other hand, introduce new functions of the robot and new concepts such as conditions and algorithmic thinking in the resolution of the problems.

Topic 10: Ta-Te-Ti. In this activity two groups of students take turns placing cards indicating their position on a 3 by 3 board. Once one group moves, the opposing group can use their positions to block the other team's positions. The group that occupies three consecutive spaces wins the game. This activity seeks to develop concepts of problem solving and debugging.

Topic 11: Yes or No! Ladder game. In this activity, students receive mathematics or general knowledge questions where the answer can be yes or no. Depending on the response, the *Irûmi* robot is presented with a different condition or situation on the board. In this activity, concepts of sequence, repetition and conditionals are developed.

Topic 12: Let's dance! In this activity, using the repetition and sound cards, students must make the *Irûmi* robot perform the repetitive movements, sounds and effects of the dance. The activity works on concepts of sequence, repetition and introduces the use of sound programming cards.

Topic 13: Password Game. In this activity the student must create passwords. To do this, she must assign a correspondence rule between numbers or letters with the programming cards.

Topic 14: Run, Irûmi! In this activity, a game is proposed where each team aims to remove the label with the name of the opposing team's robot. To do this, they must identify the locations of the robots and create mission cards, which group together more than one coding card.

Topic 15: Walk through the city. In this activity, the student determines the best route that the *Irûmi* robot should travel considering the departure point, the waypoints, and the destination. This activity allows to develop concepts such as the problem-solving algorithm.

Topic 16: Traveling through South America. On a map board of South America, the *Irûmi* robot must identify and travel the best path that will allow it to reach Paraguay. To do this, students must organize the coding cards according to the route that *Irûmi* will take.

Topic 17: Travel through space. In this activity, students must create a set of questions that will be located on the different planets on the solar system board. The team that answers the question will be able to continue with the tour of the following planets. This activity reinforces algorithmic thinking to solve problems.

Topic 18: Trip to the ocean. In this activity, questions about the ocean are created, which are located on each of the islands on the ocean board. To move from one island to the other, the student must answer the corresponding question correctly.

2.2. Educational kit

The program activities are carried out with the use of *Irûmi* intelligent robots, coding cards, tracks for robot navigation, teacher's guide, and workbooks for second-grade students. This technology was developed by the company SK Telecom, who, through the Korea Poverty Reduction Fund ("KPR")[4], donated 900 educational kits to the MEC.

Intelligent robots

The robot[5] weighs 230 grams and has a height of 13 centimeters (see Figure 1). It has autonomous navigation, LED lights, optical, light, temperature, touch and proximity sensors, speakers, and Bluetooth system. Due to these characteristics the *Irûmi* robot can move on smooth surfaces, detect obstacles at 1 to 15 cm, project many colors and emit sounds. For implementation in the classroom, the MEC provided robots to educational centers. Allocation was determined by the number of students per class, allowing, in most classrooms, a maximum of 3 students per robot.

Fig. 1 Irûmi robot

Coding cards

Each robot comes with 56 six different color coding cards, printed double-sided (see Figure 2). The cards have 22 different instructions, written in English, that allow the robot to perform simple actions, such as: move back and forth, turn on itself to the right and left, turn on or off the various colored eyes, make its own sounds or recorded, and other more complex actions such as iterations (repeat a process a certain number of times or indefinitely) and conditional structures (wait for it to detect a hand in front of it or repeat the action until this event occurs). There are four types of coding cards: i) Movement Cards: "Move Forward", "Move Backward", "Turn Right", and "Turn Left" (1 second duration); ii) Control cards: "Repeat 2 times", "Repeat 3 times", "Repeat 4 times", "Repeat forever", "End repeat", "Repeat until hand" (until [object]), "Wait" (for one second), and "Wait for hand" (for [object]); iii) Program Coding Cards: "Run Program",

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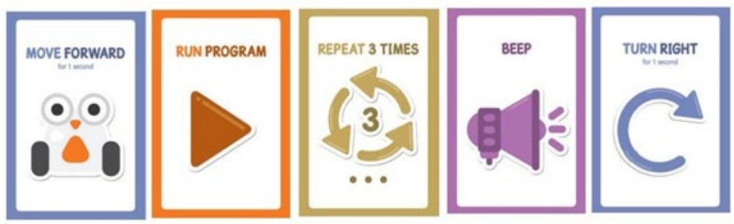
[4] The KPR Fund focuses on poverty reduction and social development, targeting the most vulnerable populations of Latin America and the Caribbean.

[5] *Irûmi* is the name that the program gave to the robot "Albert". More information about the Smart Robot Albert can be found in the Guide Book available at https://www.manualslib.com/manual/1293878/Sk-Telecom-Smart-Robot-Albert.html

“Clear Program”, and “Stop Program”; and iv) Light and Sound Cards: “Beep” (sound), “Red eyes on,” “Blue eyes on,” “Green eyes on,” “Eyes off.”, and , “Say” (say (red/green/blue)).

Fig. 2 Coding cards



Navigation boards

The *Irûmi* robot has an autonomous navigation system that allows it to move on boards, where the instructions that the students have programmed using the coding cards are executed. Navigation boards or clues were created using a special canvas that allows them to be written on with a whiteboard brush and easily erased, so that they can be personalized for each activity carried out. For each robot, a canvas track was received (see Figure 3).

Fig. 3 Navigation boards

2.3. Teacher support and training

Irûmi was designed for students in the second-grade of primary education, who developed programming and coding classes in the *contraturno*[6]. A teacher from the second grade led the program activities and was assisted by eight students

[6] In Paraguay, most public schools have a short school day of just four hours, so students attend in the morning or afternoon (Mateo-Berganza & Iribarren, 2016). So, the *contraturno* (countershift) refers to the afternoon for students who attend in the morning shift and in the morning for those who attend in the afternoon shift.

(assistants) from the third cycle of primary education[7], who provided support[8]. Classes were structured to last up to three pedagogical hours (40 minutes each) per week. The classroom activities comprise a total of 36 class hours, planned to take place in 11 weeks, from August 15 to October 29 of 2022 (See Table A1 in the Apendix for details on data of each activity in the curriculum).

Additionally, each teacher received a monthly follow-up visit from a tutor trained by OMAPA[9]. During the months of June and July of 2022, 27 tutors were trained in four training days (32 hours). The content developed was aimed at tutors correctly using the teacher manual, the student work guide, the robot, coding cards, and navigation boards. Additionally, they were trained to promote a more active work methodology in the classroom and replicate the workshops with teachers in training and in classroom accompaniment. The training was developed at the Faculty of Engineering of the National University of Asunción.

This visit was carried out with the objective of observing the teacher's performance in the implementation of the activities and providing feedback on their teaching practice. During classroom observation by the tutors, monitoring sheets were used to record various information, such as: i) the book activities that the teacher was carrying out; ii) the classroom environment, including student participation, level of involvement with activities, consultations made, support from assistants; iii) the main difficulties detected, as well as the needs or drawbacks highlighted by the teacher; iv) observations, comments or suggestions provided to the teacher.

To train teachers in the content of the program's curriculum, training and support workshops were held for teachers in schools. The teacher training consisted of implementing the 18 activities proposed in the program's curriculum. The training was carried out in 4 workshops between the months of July and September (29 hours). The workshops were implemented by the tutors. Each of the 27 tutors was assigned an average of 4 schools, with whom they conducted the workshops on dates previously

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[7] Primary education in Paraguay (Educación Escolar Básica or EEB) is aimed at students from 6 to 14 years old. It is divided into three cycles, each lasting three years. The third cycle of basic school education is intended for adolescents aged 12 to 14.

[8] The assistants were selected by directors and teachers. Student participation was not mandatory. It was recommended that the selection be based on the following criteria: i) belong to the morning shift; ii) demonstrate appropriate behavior; iii) have leadership skills; iv) possess teamwork skills; v) have interest and skills in working with second grade students; vi) have the teacher's trust; vii) have the parents' permission. Each assistant participated in an 8-hour training on program curriculum content and coding concepts and skills.

[9] The tutors are personnel trained by the OMAPA academic team. Based on interviews, 30 tutors were selected from the 7 departments of Paraguay where the participating schools are located. The chosen tutors had to meet the following requirements: i) have an interest in education, science, and innovation; ii) have completed at least high-school education. Priority was given to teachers or university students; iii) have previous experience in the classroom, especially in teacher training; iv) be available to participate in training sessions in Asunción and to carry out activities in educational institutions in their region; vi) they were not required to have prior knowledge in robotics or programming.

agreed upon with the assigned schools, according to the training schedule. To facilitate the workshops, 27 locations were set up where the training was carried out, and which were distributed in the departments where the program schools are located. If a teacher was not available on the agreed date, the tutors made an individual visit to provide the training.

3. Expected outcomes, measurement instruments and outcome variables

Table 1 describes the potential impact of the program on second-grade students' and teachers' outcomes. To measure them, different instruments available in the literature were combined and adapted.[10]

3.1. Students' outcomes

To measure the effect of *Irûmi* on second-grade students, we designed a survey that combines different instruments that aim to measure CT skills, preferences and gender attitudes to STEM toys, and attitudes toward technology.

CT Skills

To measure students' CT skills, we combined two instruments. First, a set of tasks from the Bebras International Challenge on Informatics and Computational Thinking. This challenge is designed for children and young people from 6 to 19 years old. Participants must solve problems related to computing and CT using skills such as logic, algorithmic reasoning, and problem solving[11]. Second, the Computational Thinking Test (CTT), described in Román-González et al. (2017). The objective of this test is to measure the level of CT based on the fundamental concepts of computing to solve and formulate problems. From these two instruments, a battery of 11 tasks was chosen with the purpose of evaluating the students' CT skills (See Appendix with the tasks and materials included in the CT students' test). Subsequently, we calculate a global score (CT score) that corresponds to the percentage of correct answers to the different tasks for each student. Then, to disaggregate results by CT skill we grouped the 11 tasks according to the skills evaluated. The Bebras tasks associates several CT skills with the same task. Table 2 shows the relationship between the tasks included

[10] The complete questionnaires can be requested from the authors.

[11] Bebras is an international initiative (funded in 2004 in Lithuania) aiming to promote Informatics (Computer Science, or Computing) and computational thinking among school students at all ages. One of the main activities of Bebras is the organization of the Bebras International Challenge on Informatics and Computational Thinking. The challenge is performed at schools using computers or mobile devices and the contestants are usually supervised by teachers who may integrate the challenge in their teaching activities. Different tasks are offered for five different age groups from 8 to 19 years. The Bebras challenge promotes problem solving skills and Informatics concepts including the ability to break down complex tasks into simpler components, algorithm design, pattern recognition, pattern generalization and abstraction. More information about Bebras at https://www.bebras.org/about.html. See Chiazzese et al. (2019) and Lockwood and Mooney (2018) for examples of studies using Bebras tasks to measure CT skills.

in the students' CT test and their associated skills. Finally, we measured the CT score in each skill as the average of correct answers within the tasks that measure it.

Preferences and gender attitudes to STEM toys

The literature indicates that toys are cultural products that are strongly gender stereotyped (Cherney & London, 2006; Spinner et al., 2018). For example, at ages as early as 5 years old, boys and girls show different preferences for toys (Cherney & London, 2006; Weisgram et al., 2014). These heterogeneous preferences are important because different toys induce different types of play, and different types of play are associated with differences in the development of children's social and cognitive skills (Spinner et al., 2018). In the case of *Irûmi*, the argument is more evident, since the program uses a robot, a toy traditionally associated with the male gender (Seo, 2022). On the other hand, gender flexibility refers to an "open-mindedness" about gender roles (Spinner et al., 2018). Ruble and Martin (1998) define it as "the propensity to apply an attribute to both sexes, rather than just one, or the recognition of the relative aspect of stereotypes (norms change according to culture)."

Several studies show that exposure to programming and robotics activities can improve women's interest and attitudes in this area (Gomoll et al., 2016; Master et al., 2017). Furthermore, exposure to counter stereotypical situations (e.g. girls playing with a robot) can also help change the attitudes of boys and girls (Spinner et al., 2018). Therefore, as part of the evaluation, we analyzed the effect of the program on the preferences and gender attitudes toward STEM toys. The hypothesis is that through the interaction with the robot and the exposure to counter stereotypical situations, boys and girls can change their preferences and gender attitudes toward the robot. To measure students' preferences and gender attitudes to different toys, we use two questions of the evaluation instrument from the *Pequeñas Aventureras*[12] program in Colombia. To measure preferences for STEM toys we use the question: "Do you like [name of the toy]? (yes or no)". The toys included are: i) computer; ii) robot, iii) telescope; iv) Lego; v) stethoscope, and vi) magnifying glass. Then, we created a STEM Toy Preference Index that corresponds to the average of the six dummy variables (percentage of toys preferred). To measure the gender attitude of students to STEM toys we use the question: And who plays with [name of toy], girls, boys, both? Then we created six dummy variables (1 for each toy) taking the value of 1 if the student answers "both" and 0 if answers "girls" or "boys". Finally, we created a STEM Toy Gender Flexibility Index that corresponds to the average of the six dummy variables.

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[12] *Pequeñas Aventureras* (Little Adventurers) is a multimedia program developed by Sesame Workshop with the support of Dubai Cares and the IDB. The program seeks to promote the teaching and learning of mathematics and science at the preschool level with a gender approach. More information about the program at https://desarrollo-infantil.iadb.org/es/innovaciones/region_lac/pequenas-aventureras-educacion-para-cerrar-las-brechas-entre-ninas-y-ninos

Attitudes towards technology

The attitude towards technology is an area where the program can potentially be expected to have an effect. Students, by being exposed to and interacting with educational technology, can develop affective, cognitive, and behavioral aspects in relation to it. Attitudes towards technology are relevant because literature considers them a proxy for a student's propensity to study a career in the STEM area (Svenningsson et al., 2022). To measure attitudes toward technology we calculated the Attitudes Towards Technology Index which is the average of the student degree of agreement with the following statements (1: agree; 0: disagree or neutral): i) If you had classes where a computer or robot was used in school, you would try harder in class; ii) classes would be more fun if technological devices such as computers or robots were used; iii) you would like to play and solve problems with a computer or robot; iv) you would like to participate in activities about technology, computing and robot programming that take place at school; v) you would like to know how to program a robot and how to use computers; vi) you have to be smart to study something related to technology such as robot programming or computer use; vii) only if you are good at mathematics and science can you study something related to technology such as robot programming or computer use. These questions were adapted from the Computer Attitude Questionnaire (CAQ)[13] and the Pupils Attitude Towards Technology Survey (PATT-USA)[14].

3.2. Teachers' outcomes

To measure the effect of *Irûmi* on teachers we created a survey combining different instruments that aim to measure the use of technology in the classroom, the attitudes towards new technologies in education, and CT skills.

Use of new technologies in the classroom

Since the program provided an educational kit to teachers, including a robot, it is possible for teachers to increase the use of technologies in the classroom. In this case we ask the teacher about the use of the following technologies in their teaching work: i) computers; ii) notebooks; iii) tablets; iv) radio; v) computer tools (Word, Excel, PowerPoint, Google docs); vi) digital file management spaces (Dropbox, Google Drive,

[13] CAQ is an instrument that contains 65-item Likert scale, and it is designed to measure attitudes (feelings towards a person, or a thing) and predominant attitudes (dispositions), rather than achievements. More information about CAQ in https://stelar.edc.org/instruments/computer-attitude-questionnaire-caq-0

[14] Pupils Attitude Towards Technology-survey (PATT-USA) is an instrument that contains four parts. The first asks for a brief description of what the student thinks technology is; the second consists of eleven questions on student demographic data; in the third part, 57 items are included to measure the attitude towards technology; and the fourth part is made up of 31 items related to technological concepts (Ardies et al., 2013).

OneDrive…); vii) digital resources such as educational software specialized in promoting student learning; viii) robot.

Attitudes towards new technologies in education

The rapid evolution of education requires that teachers have skills in the use of digital media, as well as integrating technology into teaching. The attitude of teachers has a significant influence on the use of these new technologies in classrooms (Atkins & Vasu, 2000). To measure this dimension, a section in the teacher questionnaire was constructed from the adaptation of the following instruments: Student Attitudes toward Technology[15] and Teachers' Attitudes Toward Computers (adapted to technology)[16]. From it, we built the Index of Attitudes Towards New Technologies in Education, which is constructed as an average of the teacher's degree of agreement (the scale for each item ranges from 1 "Strongly disagree" to 5 "Strongly agree.") with the following statements: i) learning about technological resources (e.g. computer (C)/notebook (N)/tablet (T)/etc.) is boring to me; ii) I am interested in attending technology workshops/training that involve the use of a C/N/T/etc., during my teaching career; iii) I have sufficient skills to search, select and manage information available on the Internet; iv) I feel comfortable working with a C/N/T/etc.; v) learning to use technology requires too much time and effort; vi) new technologies (e.g. C/N/T/etc.) isolate people by inhibiting normal social interactions between users; vii) new technologies (e.g. C/N/T/etc.) makes people waste too much time; viii) new technologies (e.g. C/N/T/etc.) makes a teacher's teaching more complicated/complex; ix) the use of a C/N/T/etc., could increase my productivity; x) have a C/N/T/etc. in my classroom, would help me be a better teacher; xi) the use of technology (e.g. C/N/T/etc.) would help me access more up-to-date information or resources for my students and as part of school activities; xii) the use of technology (e.g. C/N/T/etc.) could stimulate creativity in students; xiii) the use of technology (e.g. C/N/T/etc.) could help students improve their skills in math, science, etc. xiv) the use of technology (e.g. C/N/T/etc.) in the classroom would make my teaching easier; xv) the incorporation of technology (e.g. C/N/T/etc.) in the classroom would improve student learning; xvi) the use of technology (e.g. C/N/T/etc.) in the classroom would increase my productivity.

CT skills

Another possible mechanism that contributes to the impact of the program is that teachers improve their CT skills. The literature indicates that greater teacher

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[15] This instrument is included in a study that investigated how teachers' and students' technology self-efficacy and attitudes toward technology usage affect technology implementation in the classroom (Mikusa, 2015).

[16] The Teachers' Attitudes Toward Computers (TAC) questionnaire was developed during 1995-97 for a study of the effects of technology integration education on the attitudes of teachers (Christensen & Knezek, 1996). More information about TAC available at https://iittl.unt.edu/content/teachers-attitude-toward-computers-tac

knowledge about the content to be taught can improve student learning (Sadler et al., 2013). Currently, the MEC does not include CT contents in the national curriculum, so it is possible that teachers are exposed to this content for the first time. To measure teachers' CT skills, we developed a teacher test based on four tasks (Way Home 1, Trapped robot, Way Home 2, and Magic Box) (See Appendix with the evaluated tasks).

4. Experimental Design

4.1.Recruitment

To select the schools that would be part of the study, the MEC, within the framework of the Extended School Day Project (*Jornada Escolar Extendida* JEE[17]), selected 300 schools. In 131 of these schools, the extended school day modality was being implemented in both the first and second cycle[18]. The remaining 169 schools were schools where the JEE modality would be implemented, meeting the following selection criteria: i) have enough classrooms to simultaneously implement the JEE modality from the first to the sixth grade; ii) have school lunch service; iii) have connectivity provided by the MEC; iv) have, between the first and second cycles, a minimum total enrollment of 60 students. Based on the list of these 300 schools, the sample was restricted to seven departments of Paraguay (Asunción, Central, Cordillera, Guairá, Paraguarí, Misiones, and Itapúa). After this restriction, 207 schools participated in the study.

4.2. Randomization

From this 207 schools' sample, 104 were assigned to the treatment group (i.e. receives all components of the *Irûmi* program) and 103 to a control group (i.e. continue with their normal educational plan), using a stratified randomization strategy. The use of stratification allows to improve the performance of randomizations in small samples (e.g. less than 300) (Bruhn & McKenzie, 2009). The strata used were department and area (rural/urban).

4.3. Data collection: baseline and endline

The information collection instruments correspond to the questionnaires applied to second-grade students, teachers, and principals of all participating schools (207). The data collection had two stages: A baseline, in which the instruments were applied

[17] The Extended School Day Project (JEE) is a pilot program implemented in 300 schools in Paraguay, with financing from the Inter-American Development Bank, for the extension of the school day. For more information about the project see https://www.abc.com.py/nacionales/2024/03/07/lo-que-dijo-el-ministro-de-educacion-sobre-la-jornada-escolar-extendida/

[18] Primary education in Paraguay (*Educación Escolar Básica*) is divided into two cycles: The first cycle includes 1st to 3rd grade and the second cycle includes 4th to 6th grade.

before implementing the program (June 27-August 12) and an endline (October 31-December 7), where data was collected after the implementation of *Irûmi* to estimate its impact on students and teachers.

5. Sample characteristics and Econometric Models

5.1. Sociodemographic characteristics of the sample and balance validation

Randomized control trials base the identification strategy of the causal impact of an intervention on the generation of comparable groups (Duflo et al., 2007). Using the data collected at the baseline, we tested if treatment and control groups were statistically identical. Table 3 presents a set of variables of schools, second-grade students, and teachers and the p-value of a two-tailed test on the hypothesis that the averages of the treatment and control groups are equal. For most of the variables we found no statistically significant differences between the treatment and control groups. Of all the variables compared, only two present statistically significant differences, which is to be expected from a random process: the control group has a slightly higher proportion of female teachers (86.7% vs 75.6%) and a greater probability of having received training in science (67.4% vs 53.4%) than the treatment group.

5.2. Econometric models

To evaluate the effects of the *Irûmi* program we estimate the following equation using ordinary least squares (OLS):

$$\text{(a)} \qquad Y_{ij} = \mu_s + \beta_1 Y_{ij,t-1} + \beta_2 T_j + \beta_3 X_{ij} + \epsilon_{ij}$$

where Y_{ij} is the outcome of interest for student or teacher *i* at school *j*, $Y_{ij,t-1}$ is the same outcome measured at the baseline, T_j is a dummy variable that takes the value 1 if the school is part of the treatment group and 0 when it is part of the control group, X_{ij} is a vector of control variables measured at the baseline. In the case of students, they include student characteristics (age, sex) and school characteristics (number of classrooms, infrastructure status and a school global index), and ϵ_{ij} is the error term. The inclusion of $Y_{ij,t-1}$ and X_{ij} in the model allows us to reduce residual variance and improve statistical power (Imbens & Wooldridge, 2009). The estimated parameter β_2 captures the causal effect of the treatment on the outcome of interest. For all specifications we include fixed effects by strata (μ_s) to incorporate the randomization strategy in the model, which allows us to gain efficiency (Bruhn & McKenzie, 2009). Additionally, we cluster the standard errors at the cluster level, allowing for correlation between the errors of students in the same school. Grouping standard errors allows us to avoid "excess rejection" (Bertrand et al., 2004).

Following the impact evaluation literature β_2 is the Intention to Treat Effect (ITT). The ITT is the effect of the program on those assigned to treatment, regardless of their take-up. In many cases, researchers, and policy makers care about the impact of the offer of the program, as this will resemble what will be likely to happen if the program is rolled out. For this reason, this estimator is also known as the "policy impact" of the program (Gertler et al., 2016). To study the heterogeneous effects of *Irûmi*, conditional on the characteristics of the sample, we estimate the following equation:

$$\text{(b)} \qquad Y_{ij} = \mu_s + \beta_1 Y_{ij,t-1} + \beta_2 T_j + \beta_3 X_{ij} + \beta_4 H + \beta_5 T_{ij} H + \epsilon_{ij}$$

Where H are dichotomous variables that define characteristics of students, schools, or teachers, and β_5 is the additional effect for the included category with respect to the effect on the omitted one (β_2).

All the outcome variables presented in the Results section (see definitions in the section Expected outcomes, measurement instruments and outcome variables) were standardized using the following formula:

$$\text{(c)} \qquad Z_{ij} = (Y_{ij} - \mu_c)/\sigma_c$$

where, Y_{ij} represents the value of the outcome variable for student i in school j, μ_c represents the mean of the control group, and σ_c is the standard deviation of the control group. Standardizing variables is a common practice in educational interventions because it allows the results to be converted into a common unit such as standard deviations. Given this transformation, β_2 measures the estimated ITT expressed as standard deviations (SD) of the control group[19].

6. Results

6.1. Implementation of *Irûmi*

Overall, the program had a high level of implementation with respect to what was planned[20]. Regarding materials, 99% of participating schools received the complete *Irûmi* kit (robot, coded cards, USB cables for charging, navigation boards or canvas track, *Irûmi* student manual, *Irûmi* teacher guide, multi-charger and stationery). Regarding teacher training workshops, 69% of them participated in the four workshops, 23% in three, 6% in two and 2% in one. About them, 87% of participants perceived them as useful or very useful and 83% were satisfied or very satisfied with their content. Variations in the amount of training received by teachers may have

[19] The only exception are the results in Table 9, where the effect of the program is expressed as percentage points (differences in probability).
[20] The content of this subsection is a summary of data on the implementation of the program. More specific details can be obtained from the authors upon request.

affected treatment homogeneity and should be considered when reading the results discussed in subsections 6.2. and 6.3. As regards the implementation of the program in the classroom, 96% of teachers reported having carried out the activities contemplated in the school plan. However, there was variation in the weekly hours dedicated: 12% of teachers reported having conducted 1 hour of class per week with the *Irûmi* robot, 33% 2 hours, 16% 3 hours, 23% 4 hours, and 11% more than 5 hours. Although 25% of schools had delays in the delivery of materials and 35% had started implementing the program later than expected, the average number of activities completed was 14.7 (out of a total of 18), i.e. 82% of the expected content. However, there was also variation in this indicator. 58% of teachers reported having completed all the activities, 21% more than 75%, 13% between 50% and 75%, and 7% less than 50%. Among the teachers who implemented their classes using *Irûmi* materials, 77% reported that they had no difficulties during classroom sessions. However, the remaining 21% reported having had difficulties in the development of the classes. The most common problems included low attendance of second grade students, schedules, and lack of time to develop activities. The ratio of students per robot was close to the expected (3 students per robot), with only 18% of teachers reporting a ratio greater than 3.5 students per robot. On the other hand, only 14% of schools had any problems when it came to getting the robots to work.

In terms of support, 41% of schools received visits from OMAPA tutors during the implementation of the program in the classroom (95% received one visit and 5% two visits). Perhaps the support component that presented the most difficulties was that of the assistants, where although the expected number of assistants was recruited, only 67% of them participated in the two training workshops and 59% participated in all classes supporting the teacher. One of the main difficulties was that not all the assistants came from the treated school (some of them did not have students in the third level of primary school) reducing the probability that they would be transported to the school where they were to provide support. Another difficulty was that some schools did not have a school food service, so the assistants went home and did not return.

The limitations in support could explain why only 43% of the teachers reported that it was easy or very easy to follow the program, although this number rises when they are asked specifically about the use of the robot. In this case, 64% reported that the use of the robot was easy or very easy and 71% considered that it was easy or very easy to get the robot to interact with the student. Even so, both teachers and students had a very positive perception of the program. 100% of the teachers declared that the program was useful to teach children programming concepts and 99% stated that it increased the participation of the students in class. On the other hand, 98% of students reported that they liked the classes with the robot and 99% that they would like to continue receiving classes with the robot. Finally, the data suggests that teachers in rural areas and men may have faced greater difficulties in the implementation.

6.2. Effects on students' outcomes

CT skills

Table 4 presents the impact of *Irûmi* on students' CT skills, obtained by estimating equation (a) with the student sample. Results suggests that the program had an impact of 0.089 standard deviations (SD) on the students' CT score, which is encouraging considering that the program was designed to be implemented for a period of only 3 months (36 hours in total), and that, on average, the schools carried out 14.7 of the 18 sessions, that is, 82% of the planned content[21]. Table 5 shows the estimated effect of *Irûmi* for each CT skill measured by the CT test. The results suggest that the impact is explained by an improvement in abstraction (0.136 SD), algorithmic thinking (0.086 SD), and evaluation skills (0.143 SD). Additionally, we observed a slight negative effect on the debugging skill (-0.081). Finally, Table 6 presents the impacts of the program disaggregated by the tasks of the CT test. The results indicate that the effect of the program is concentrated in three tasks: Puzzle 1 (0.075 SD), Moving ball (0.050 SD) and Way home 2 (-0.039 SD). The negative effect on the Moving ball task is consistent with the negative impact on the debugging skill since this task is designed to measure this skill.

Preferences and gender attitudes to STEM toys

Table 7 shows the heterogeneous effect (equation (b)) of *Irûmi* on preferences for STEM toys (STEM Toy Preference Index) and on students' gender attitudes towards STEM toys (Gender Flexibility Index), according to the student's sex. Regarding preferences for STEM toys, the results indicate that the program had a slight positive, but not statistically significant, effect on boys (0.022 SD). However, in the case of girls the impact is positive and statistically significant. In this case *Irûmi* increased the STEM Toy Preference Index by 0.152 SD (0.022 SD + 0.130 SD). The results are similar when considering the impact of the program on the STEM Toy Gender Flexibility Index. In the case of boys, the effect is 0.009 SD, but it is not statistically significant. On the contrary, among girls the *Irûmi* program increased gender flexibility by 0.196 SD (0.009 SD + 0.187 SD).

[21] To examine the robustness of all the estimations of the impact of the program on CT skills, we tested alternative calculation of the scores. First, eliminating the observations that have a missing value in any of the tasks; and second, imputing 0 to the missing values. The results of these estimates, which can be requested from the authors, show robustness in the estimation of the impact of the program on CT skills.

Attitudes towards technology

Table 8 presents the estimate of the impact of the program on the students' attitudes towards technology, showing that the students in the treatment group increased their positive attitudes toward technology by 0.23 SD above the control group.

6.3. Effects on teachers' outcomes

Use of new technologies in the classroom

Table 9 presents the estimation of the impact of *Irûmi* in the probability that the teacher uses different technological tools in the classroom, based on equation (a). Results indicate that teachers in the treatment group increased 82 percentage points (pp) the probability of using a robot with respect to control teachers. This result confirms that teachers have incorporated the robot as part of their classroom pedagogy. An interesting result is that teachers also reported an increase in the probability of using notebooks (laptops[22]) of 18 pp. The *Irûmi* program did not include the use of these notebooks as part of its strategy, which suggests that there was potentially a spillover effect of the program on the use of other technological tools.

Attitudes towards new technologies in education

Table 10 shows the estimated effect of the program on teachers' attitudes towards new technologies, using equation (a). The results indicate that *Irûmi* had a positive impact of 0.293 SD on the Index of Attitudes Towards New Technologies in Education. This result suggests that the program generated a more positive attitude towards educational technology, which, hypothetically, may have motivated teachers to not only use the *Irûmi* robot, but also incorporate other technologies in the classroom.

CT skills

Table 11 shows the estimated impact of *Irûmi* on each of the 4 tasks included in the teachers' CT test, based on equation (a). The results indicate that the effect of the program is concentrated in the "Way Home 1" (0.155 SD) and "Trapped robot" (0.206 SD) tasks, which measure algorithmic thinking (consistent with the effect found in the student CT test) and automation skills respectively.

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[22] In recent years, the MEC has invested in several initiatives aimed at delivering notebooks to schools. Go to https://www.ip.gov.py/ip/mec-entrego-mas-de-650-notebooks-a-instituciones-educativas-de-central/ for an example of these initiatives.

7. Discussion

In this article we present the results of the impact evaluation of *Irûmi*, an educational program aimed to develop CT skills in second-grade students of public primary education in Paraguay.

Our results suggest that the program had an impact on the students' CT skills despite its short duration (36 hours in 3 months), and that, on average, only 82% of the planned contents were implemented by the teachers. The effect was 0.09 standard deviations and focuses on skills such as abstraction, algorithmic thinking, and evaluation (according to Bebras' classification). This effect is in the middle range of the distribution of effects of education interventions (Kraft, 2020).

Results in this dimension are consistent with the main findings of the empirical literature. First, that with age-appropriate instructional design, young children could develop early concepts and skills of CT and, second that smart devices and electronic toys (e.g. robots) can contribute to the development of these skills in ECE. Our study contributes to this literature because it is applied to a middle-income country, uses an experimental design with a control group, pre- and post-treatment measures, and a large student sample, and explores program impact not only on students but also on teachers.

Our findings are also relevant to the discussion on how to incorporate CT into school curricula in Latin America. Although there are various initiatives in the region aimed at introducing CT concepts and skills into the classroom—many of which are based on the use of educational robots—the literature highlights several challenges in formally integrating CT into school curricula (Curasma & Curasma, 2020; Quiroz-Vallejo et al., 2021). First, there is a lack of a more comprehensive definition of CT and its associated skills, extending beyond knowledge exclusively related to computer science. Second, there is a shortage of rigorous quantitative research on the impact of interventions designed to develop CT skills in students and teachers, which could serve as a foundation for its integration into the school curriculum. Our study contributes to bridging the knowledge gap in both dimensions.

Irûmi not only had an impact on students' CT skills, but also on other dimensions for which it may not have been intentionally designed, but which by its design allows it to be addressed. We found that the program raises preferences towards STEM toys (including the robot) and enables the development of gender flexibility toward who can play with these toys, especially among girls.

These results suggest that a program that develops CT skills using educational technology, in this case robots, can mitigate pre-existing gender biases. Our finding is consistent with a recent study showing that a developmentally appropriate robotics curriculum can increase girls' interest in engineering during early elementary school

(Sullivan & Bers, 2019). Finally, consistent with the literature, we found that the program also contributed to increasing children's positive attitudes toward technology, which could have implications for their future educational decisions and investments (e.g. to study a career in the STEM area).

The mechanisms by which the effects of *Irûmi* occur are several. First, the program increased the probability that the teacher would use educational technology in the classroom, including devices that were not contemplated by the program such as notebooks (spillover effect). This result can be explained by the fact that the program also increased teachers' positive attitudes towards the use of technologies in the classroom. However, this relationship between teacher attitudes and the effective use of new technologies in the classroom should be evaluated in future studies. Second, we found that the program allowed teachers to develop their CT skills, possibly due to the novelty of the curriculum and methodology. This is relevant from an educational policy point of view, because there is a broad consensus that CT teachers should be provided with training opportunities focused on CT pedagogy and hands-on learning which can be easily transferred to the classroom (Bocconi et al., 2016). Based on the participants teachers' own opinions, the training and school planning component may be one of the reasons for *Irûmi* 's positive impact on teachers and students.

Despite the positive effects of *Irûmi* on the students' CT skills, the program had no impact on some specific abilities (e.g. decomposition, abstraction, and automation) and a small negative effect on the debugging skill.

Two hypotheses could explain this finding. First, there are challenges in the design and implementation of instruments to measure some CT skills in early childhood, due to a lack of consensus on CT frameworks and definitions (Su & Yang, 2023; Bocconi et al., 2016)**.** Second, there is evidence that children may have difficulty to develop some advanced CT concepts (e.g., iterations, conditionals or debugging) at a young age (Bakala et al., 2021; Su & Yang, 2023). Some authors suggest that this is due to differences in mental development between children of different ages. In particular, very young children had less development of working memory, which is defined as the ability to internally collect and use information simultaneously over a short period of time. On the other hand, there is evidence that this ability is not easily developed with interventions at this age (Bati, 2022).

Future research should address several questions that could complement our results. First, given the short implementation time of the program, it is necessary to measure medium- and long-term impact of *Irûmi* on CT skills and other non-cognitive outcomes, to find out if the positive effects of the program remained after its end. Second, it is important to evaluate the impact of the intervention in contexts other than the one used in our evaluation. Third, it could be useful to study the relation between CT skills and student learning in other areas of the curriculum such as mathematics, science, and language to test possible complementarities. Finally, it is necessary to study the mechanisms behind the program's impact on girls' preferences and attitudes toward STEM toys. This analysis is essential to design interventions that reduce gender inequities and biases in the teaching of CT.

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Tables

Table 1. Second-grade students' and teachers' outcomes potentially impacted by *Irûmi*

Level	Outcome
Students	Computational Thinking (CT) skills
	Preferences and gender attitudes to STEM toys
	Attitudes towards technology
Teachers	Use of new technologies in the classroom
	Attitudes towards new technologies in education
	Computational Thinking (CT) skills

Table 2. Computational Thinking (CT) skills and related tasks in the students' CT test

Tasks	CT skills						
	Decomposition	Abstraction	Algorithmic Thinking	Automation	Debugging	Generalization	Evaluation
Bird house	x	x	x				
Puzzle 1 (4 pieces)		x					x
Puzzle 2 (5 pieces)		x					x
Honey pot			x				x
Moving ball			x				
Trapped robot			x				
Way home 1				x			
Organize the shelf	x		x				x
Way home 2					x		
Wooden animals		x	x			x	
Fix the bracelet							x

Table 3. Sample characteristics and balance validation

Variable	Control	Treatment	All	p-value	N
School characteristics					
Infrastructure status: poor	0.087	0.106	0.097	0.619	207
Infrastructure status: regular	0.223	0.24	0.232	0.722	207
Infrastructure status: good	0.689	0.654	0.671	0.518	207
Enough classrooms	0.951	0.952	0.952	0.993	207
Number of classrooms	6.816	6.683	6.749	0.617	207
School global index	7.748	7.448	7.597	0.294	207
Second-grade students					
Age (years)	7.342	7.358	7.35	0.450	2,040
Sex: Woman	0.516	0.508	0.512	0.625	2,040
CT score	0.000	-0.011	-0.006	0.822	2,040
STEM Toy Preference Index	0.000	-0.033	-0.017	0.418	2,040
STEM Toy Gender Flexibility Index	0.000	0.035	0.018	0.497	1,964
Attitudes Towards Technology Index	0.000	-0.009	-0.004	0.806	2,040
Teacher					
Sex: Woman	0.867	0.756	0.811	0.039**	180
Age	43.412	42.716	43.064	0.422	180
Education: uncomplete primary	0.000	0.011	0.006	0.314	180
Education: complete primary	0.122	0.144	0.133	0.713	180
Education: complete secondary	0.022	0.011	0.017	0.662	180
Education: diploma, technician or teacher	0.444	0.467	0.456	0.777	180
Education: uncomplete tertiary	0.067	0.078	0.072	0.729	180
Education: complete tertiary	0.289	0.267	0.278	0.723	180
Education: master's or doctorate	0.056	0.022	0.039	0.238	180
Training: have received training for science teaching	0.674	0.534	0.605	0.060*	177
Training: have received training for programming teaching	0.411	0.411	0.411	0.965	180
Training: have received training for mathematics teaching	0.722	0.700	0.711	0.713	180
Employment: full-time	0.956	0.989	0.972	0.194	180
Employment: part-time	0.044	0.011	0.028	0.194	180
Language of instruction: only Spanish	0.056	0.044	0.050	0.733	180
Language of instruction: mainly Guaraní	0.011	0.011	0.011	0.933	180
Language of instruction: mainly Spanish	0.211	0.278	0.244	0.287	180
Language of instruction: both equally	0.656	0.600	0.628	0.426	180
Language of instruction: Jopará	0.067	0.067	0.067	0.980	180
Index of Attitudes Towards New Technologies in Education	0.000	-0.183	-0.092	0.240	180
CT score	0.000	0.181	0.091	0.232	180

Notes: Columns 1–3 show averages for all observations. Column 4 reports p-values from two-tailed tests of equality. Column 5 shows the number of observations. Standard errors are clustered at the school level. Regressions include strata fixed effects. ***, **, and * indicate significance at 1%, 5%, and 10%.

Table 4. Estimated impact of *Irûmi* on students' CT score (in standard deviations SD)

Variable	CT score Coefficient/(SE)
Treatment (T)	0.089* (0.052)
CT score (baseline)	0.328*** (0.025)
Observations (N)	1,871

Notes: The coefficient was obtained from a regression that controls for the CT score obtained at baseline, the characteristics of the students (age, sex) and the characteristics of the schools (number of classrooms, infrastructure status and a global school index). The observation unit is the student. All regressions include fixed effects for the strata used in randomization and standard errors (SE) (in parentheses) are robust and have been clustered at the school level. ***, ** and * indicate the level of statistical significance at 1%, 5%, and 10% respectively.

Table 5. Estimated impact of *Irûmi* on different students' CT skills (in standard deviations SD)

Variable	CT skills						
	Decomposition	Abstraction	Algorithmic Thinking	Automation	Debugging	Generalization	Evaluation
Treatment (T)	0.074	0.136***	0.086*	-0.060	-0.081*	-0.009	0.143***
	(0.047)	(0.050)	(0.049)	(0.048)	(0.048)	(0.046)	(0.049)
Observations	1,871	1,871	1,871	1,871	1,840	1,871	1,871

Notes: This table reports the impact of the *Irûmi* program on each CT skill. Control variables include same skill measured at baseline, student characteristics (age, sex), and school characteristics (number of classrooms, infrastructure status, and a global school index). The unit of observation is the student. All regressions include fixed effects for the strata used in randomization and standard errors (in parentheses) are robust and have been clustered at the school level. ***, ** and * indicate the level of statistical significance at 1%, 5%, and 10% respectively.

Table 6. Estimated impact of *Irûmi* on different tasks of the students' CT test (in standard deviations SD)

CT test task	Coefficient/(SE)	Observations (N)
Bird house	0.030	1,871
	(0.019)	
Puzzle 1	0.075***	1,870
	(0.021)	
Puzzle 2	0.036	1,871
	(0.025)	
Honey pot	0.014	1,863
	(0.019)	
Moving ball	0.050**	1,871
	(0.021)	
Trapped robot	-0.001	1,871
	(0.017)	
Way home 1	-0.028	1,871
	(0.023)	
Organize the shelf	0.019	1,871
	(0.022)	
Way home 2	-0.039*	1,840
	(0.023)	
Wooden animals	-0.004	1,871
	(0.022)	
Fix the bracelet	0.020	1,862
	(0.023)	

Notes: This table reports the impact of the *Irûmi* program on each task of the students' CT test. Control variables include same task measured at baseline, student characteristics (age, sex) and school characteristics (number of classrooms, infrastructure status and a global school index). The observation unit is the student. All regressions include fixed effects for the strata used in randomization and standard errors (SE) (in parentheses) are robust and have been clustered at the school level. ***, **, and * indicate the level of statistical significance at 1%, 5%, and 10% respectively.

Table 7. Estimated impact of *Irûmi* on students' preferences and gender attitudes to STEM toys by student's sex (in standard deviations SD)

Variable	STEM Toy Preference Index	STEM Toy Gender Flexibility Index
	Coefficient/(SE)	Coefficient/(SE)
Treatment (T)	0.022	0.009
	(0.063)	(0.071)
Sex (woman=1)	-0.080	0.014
	(0.056)	(0.065)
Treatment (T) x Sex (woman=1)	0.130*	0.187*
	(0.077)	(0.096)
Observations (N)	1,871	1,871

Notes: This table reports the heterogeneous effect of the program on preferences and gender flexibility to STEM toys according to the student's sex. Regression controls for the baseline variable, student characteristics (age, sex) and school characteristics (number of classrooms, infrastructure status and a global school index). The unit of observation is the student. All regressions include fixed effects for the strata used in randomization and standard errors (SE) (in parentheses) are robust and have been clustered at the school level. ***, **, and * indicate the level of statistical significance at 1%, 5%, and 10% respectively.

Table 8. Estimated impact of *Irûmi* on students' attitudes toward technology (in standard deviations SD)

Variable	Attitudes Towards Technology Index
	Coefficient/(SE)
Treatment (T)	0.228***
	(0.047)
Attitudes Towards Technology Index (baseline)	0.222***
	(0.025)
Observations (N)	1,871

Notes: This table reports the impact of the *Irûmi* program on the Attitude Towards Technology Index. The regression controls for the index obtained at baseline, student characteristics (age, sex), and school characteristics (number of classrooms, infrastructure status, and a global school index). The unit of observation is the student. Regression includes fixed effects for the strata used in randomization and standard errors (SE) (in parentheses) are robust and have been clustered at the school level. ***, **, and * indicate the level of statistical significance at 1%, 5%, and 10% respectively.

Table 9. Estimated impact of *Irûmi* on the probability that teachers use new technologies in the classroom (in percentage points)

Variable	Technological tools							
	computers	notebooks	tablet	radio	computer tools	digital file management spaces	educational software	robot
Treatment (T)	0.076	0.179**	0.048	-0.028	-0.015	0.007	0.082	0.816***
	(0.081)	(0.074)	(0.044)	(0.083)	(0.074)	(0.083)	(0.082)	(0.046)
Observations (N)	160	160	160	160	160	160	160	160

Notes: This table reports the impact of the *Irûmi* program on the probability that teachers use different technological tools in their teaching work. For each tool, the dependent variable corresponds to a dummy that takes the value 1 if the teacher declares using the tool in his teaching work and 0 otherwise. Computer tools refer to: Word, Excel, PowerPoint, Google Docs; Digital file management spaces refer to: Dropbox, Google Drive, OneDrive. Control variables include teacher characteristics (age, sex) and school characteristics (number of classrooms, infrastructure status, and a global school index). The unit of observation is the teacher. All regressions include fixed effects for the strata used in randomization and standard errors (SE) (in parentheses) are robust and have been clustered at the school level. ***, **, and * indicate the level of statistical significance at 1%, 5%, and 10% respectively.

Table 10. Estimated impact of *Irûmi* on teachers' attitudes towards new technologies in education (in standard deviations SD)

Variable	Index of Attitudes Towards New Technologies in Education
	Coefficient/(SE)
Treatment (T)	0.293*
	(0.156)
Index of Attitudes Towards New Technologies in Education (baseline)	0.416***
	(0.074)
Observations (N)	160

Notes: This table reports the impact of the *Irûmi* program on the Index of Attitudes Towards New Technologies in Education. Control variables include: the baseline variable, teacher characteristics (age, sex), and school characteristics (number of classrooms, infrastructure status, and a global school index). The unit of observation is the teacher. All regressions include fixed effects for the strata used in randomization and standard errors (SE) (in parentheses) are robust and have been clustered at the school level. ***, **, and * indicate the level of statistical significance at 1%, 5%, and 10% respectively.

Table 11. Estimated impact of *Irûmi* on different tasks of the teachers' CT test (in standard deviations SD)

Task	Coefficient/(SE)	Observations (N)
Way home 1	0.155*	160
	(0.081)	
Trapped robot	0.206**	160
	(0.077)	
Way home 2	0.028	160
	(0.074)	
Magic box	-0.104	160
	(0.078)	

Notes: This table reports the impact of the *Irûmi* program on the score in each of the teachers' CT test tasks. Controls include the baseline score, teacher characteristics (age, sex), and school characteristics (number of classrooms, infrastructure status, and a global school index). The unit of observation is the teacher. All regressions include fixed effects for the strata used in randomization and standard errors (in parentheses) are robust and have been clustered at the school level. ***, **, and * indicate the level of statistical significance at 1%, 5%, and 10% respectively.

Appendix

Table A1. Irûmi Program Curriculum

<table>
<tr><th colspan="5">Activities</th><th>Teachers' workshop</th><th>Assistants' workshop</th><th>Classroom lessons</th></tr>
<tr><td>Category</td><td>No</td><td>Activity</td><td>Organizing Principle</td><td>Hours (#)</td><td>No.</td><td>No.</td><td>Week</td></tr>
<tr><td rowspan="8">Disconnected Activities</td><td rowspan="2">1</td><td>Move!</td><td rowspan="2">Sequence</td><td rowspan="2">1</td><td rowspan="9">Project launch and Workshop 1</td><td rowspan="15">Workshop 1</td><td rowspan="8">Week 1</td></tr>
<tr><td>Let's be a robot</td></tr>
<tr><td rowspan="2">2</td><td>Move!</td><td rowspan="2">Sequence</td><td rowspan="2">1</td></tr>
<tr><td>Capture of dolls</td></tr>
<tr><td rowspan="2">3</td><td>Move!</td><td rowspan="2">Sequence/ Repetition</td><td rowspan="2">1</td></tr>
<tr><td>Land conquest game</td></tr>
<tr><td rowspan="2">4</td><td>Move!</td><td rowspan="2">Sequence/ Repetition</td><td rowspan="2">1</td></tr>
<tr><td>Box construction game</td></tr>
<tr><td rowspan="5">Familiarization Activities</td><td>5</td><td>Say hello to your robot friend!</td><td>Basic function</td><td>2</td><td rowspan="2">Week 2</td></tr>
<tr><td>6</td><td>Say hello to your robot friend!</td><td>Sequence</td><td>2</td><td rowspan="5">Workshop 2</td></tr>
<tr><td>7</td><td>Playing to eat candies</td><td>Sequence</td><td>2</td><td rowspan="2">Week 3</td></tr>
<tr><td>8</td><td>Who is good at this?</td><td>Sequence/ Repetition</td><td>2</td></tr>
<tr><td>9</td><td>Draw!</td><td>Sequence</td><td>2</td><td rowspan="2">Week 4</td></tr>
<tr><td rowspan="2">Reinforcement and new topics</td><td>10</td><td>Ta-Te-Ti</td><td>Sequence/ Repetition</td><td>3</td></tr>
<tr><td>11</td><td>Yes or No! Ladder game</td><td>Sequence/ Repetition/ Condition</td><td>3</td><td>Workshop 3</td><td>Week 5</td></tr>
</table>

	12	Let's dance!	Sequence/ Repetition/Sound	2			
	13	Password Game	Sequence/ Repetition/ Sound/LED	2		Workshop 2	Week 6
	14	Run, Irûmi!	Sequence/ Repetition/ Sound/LED	3			Week 7
	15	Walk through the city	Problem-solving algorithm	3	Workshop 4		Week 8
	16	Traveling through South America	Problem-solving algorithm	3			Week 9
	17	Travel through space	Problem-solving algorithm	3			Week 10
	18	Trip to the ocean	Problem-solving algorithm	3			Week 11

Student's CT test tasks

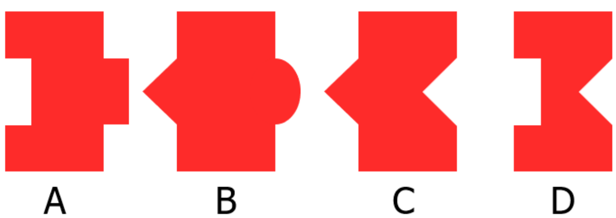
Task 1: Bird house

"Look, in this game you must help Julia, she wants to buy a bird house for her daughter's birthday. Her daughter told him: "For my birthday I would like a bird house with a window, a heart and a star."
"Which birdhouse should Julia buy?"

Correct answer: House 3

Task 2: Puzzle 1 (4 pieces)

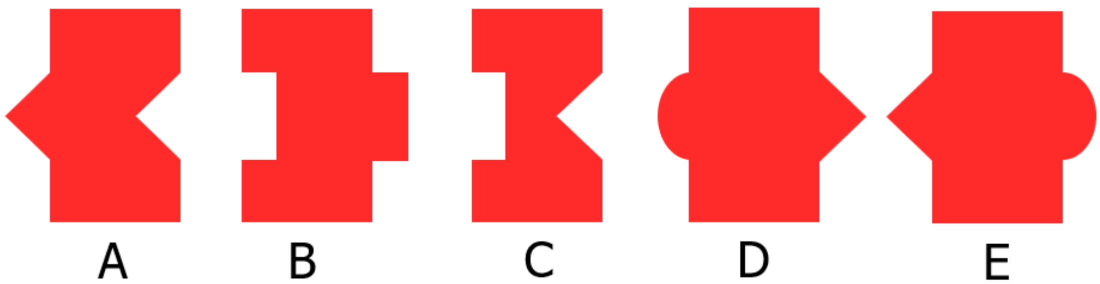
"Look, this is a puzzle that has four pieces [POINT TO THE PIECES] that are separate, and you must fit them together or put them together. In what order do the pieces come together to assemble the puzzle?" [PUT THE PIECES ON THE TABLE IN THE ORDER INDICATED BELOW]



Correct answer: A D C B

Task 3: Puzzle 2 (5 pieces)

"Look, here we have 5 pieces [POINT TO THE PIECES] of a puzzle. To assemble the puzzle, you just must select 4 pieces [POINT FOUR FINGERS WITH HAND] that are now separated, but you must fit or join them. In what order do the 4 pieces come together to assemble the puzzle?" [PUT THE PIECES ON THE TABLE IN THE ORDER INDICATED BELOW]

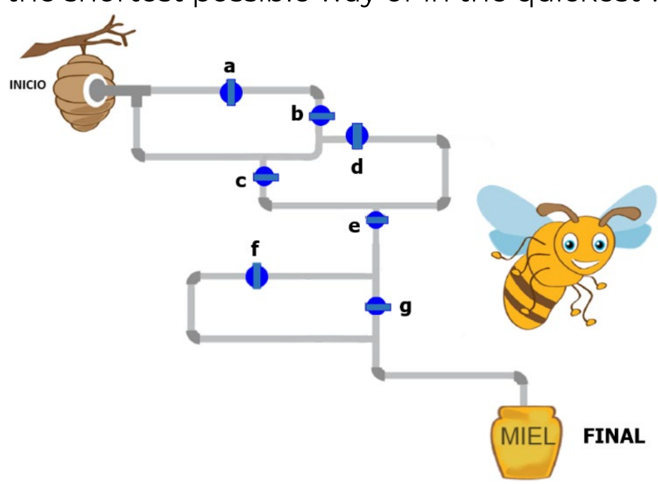


Correct answer: B C A E

Task 4: Honey pot

"Look, this is Antonia the bee and her honeycomb with honey [POINTING TO HONEYCOMB AND POINTING TO HONEY JAR]. In this game Antonia wants the Honey to go from the honeycomb to the honey jar through the pipes." [POINTING TO THE PIPES]

"Mark the taps [POINT THE TAPS] that Antonia needs to open so that the honey reaches the jar in the shortest possible way or in the quickest way possible."

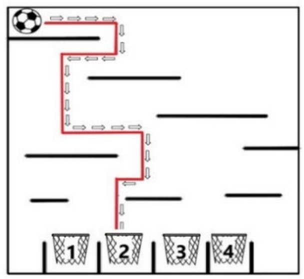


Correct answer: C E G

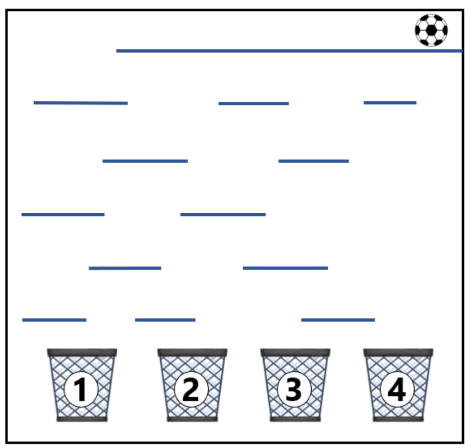
Task 5: Moving ball

"Look, in this maze the ball [POINT TO THE BALL] falls through the floors [POINT TO THE FLOORS] and the condition is that every time it falls to a new floor it changes direction. That is, if the ball first starts going to the right and falls to a new floor, then it will change direction and go to the left."

"Remember, every time the ball falls to a new floor it changes direction." [POINT THE CHANGE OF DIRECTION IN THE EXAMPLE WHILE NARRATING THE TEXT]. [DEVELOP EXAMPLE]



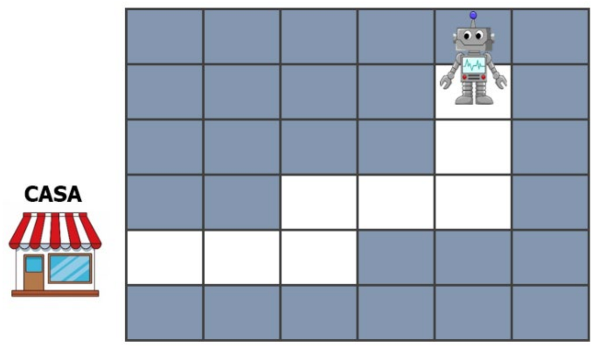
In this new maze, which basket will the ball reach?



Correct answer: 1

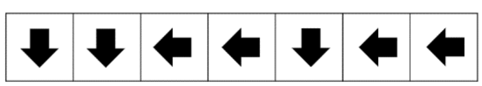
Task 6: Trapped robot

"Look, in this game you must help the robot [POINT TO THE ROBOT] to get to his house [POINT TO THE HOUSE] following the path of the white squares [POINT TO WHITE SQUARES]. You can use these directions as many times as you need" [POINT TO THE ARROW CARDS AND THEN SAY THE FOLLOWING, POINTING TO THE ARROW OPTIONS ON THE SHEET]. This arrow means that the robot is going to the right. [POINT FIRST ARROW 1]. This arrow means the robot is going down. [POINT SECOND ARROW 2] This arrow means that the robot is going to the left. [POINT THIRD ARROW 3]. This arrow means the robot is going up. [POINT LAST ARROW 4]



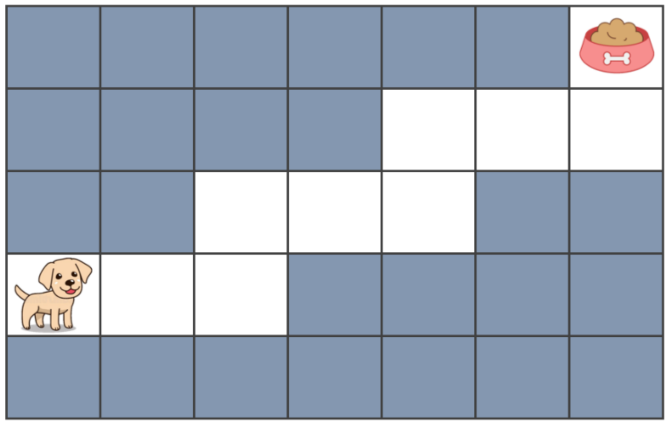
"Now it's your turn, using the arrow cards (GIVE HIM THE ARROW CARDS) you must tell me which set of arrows helps the robot find its house?

Correct answer:

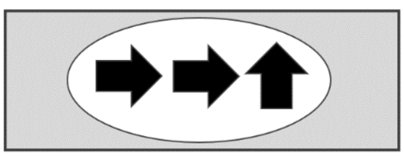


Task 7: Way home 1

"Look, in this game you must help the dog find his food bowl [POINT TO THE DOG AND FOOD BOWL] following the path of the white squares [POINT PATH OF WHITE SQUARES]. This card [SHOW CARD 1] indicates a sequence of steps that will be repeated through the path of the white squares."



How many times do you have to repeat this card [SHOW CARD 1] so the dog can find his food bowl?



Correct answer: three times

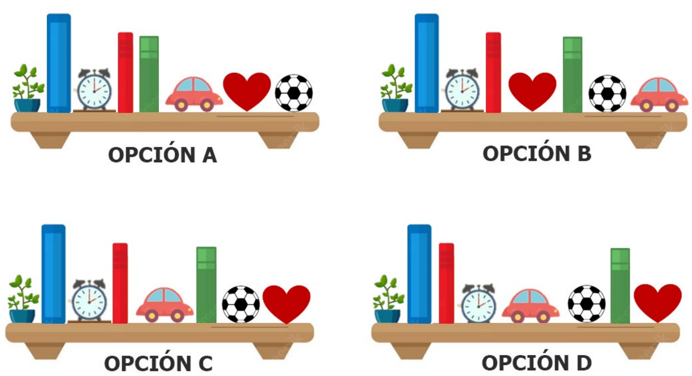
Task 8: Organize the shelf

"Look, in this game you must help Beatriz, she wants to organize her shelf, but she has two rules to organize it:

1. The first rule is that books [POINT BOOKS] should not be next to each other, and
2. The second rule is that the ball [POINT BALL] should not be next to the toy car.

Which of the following shelves has followed Beatriz's rules?

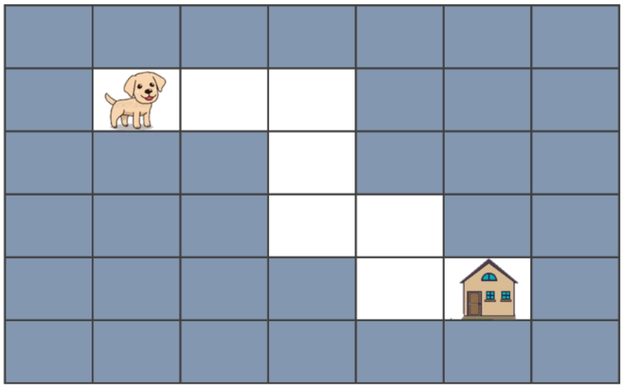
Remember: Books should not be next to each other, and the ball should not be next to a book



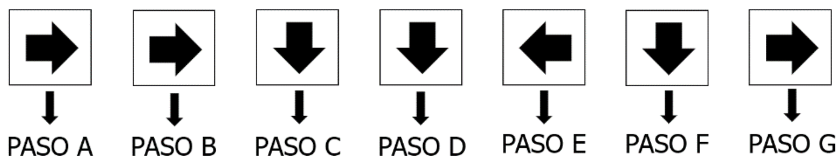
Correct answer: C

Task 9: Way home 2

"Look, in this game for the dog to get to the house [POINT TO THE DOG AND THE HOUSE] he must follow the path of the white squares [POINT TO THE PATH OF WHITE SQUARES]



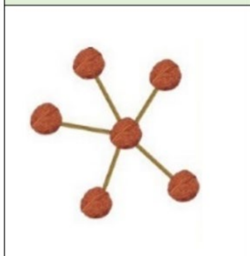
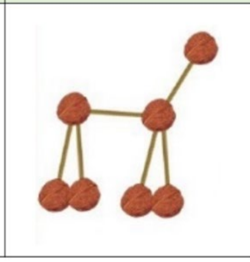
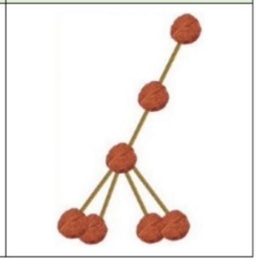
"But he is lost because one of the steps he has to follow is incorrect [POINT TO THE STEPS], and now you have to help the dog identify which step is wrong."



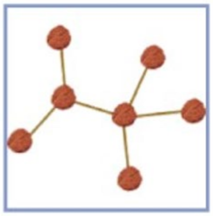
Correct answer: E

Task 10: Wooden animals

"Look, in this game María was playing in the forest with sticks and balls and created three figures: a star [POINT TO THE STAR], a dog [POINT TO THE DOG] and a giraffe [POINT TO THE GIRAFFE]. But her sister destroyed the figures without removing any of the sticks or balls. María is very upset because she really liked the star figure."

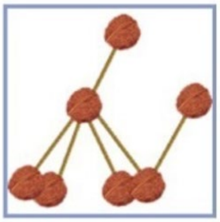
ESTRELLA	PERRO	JIRAFA
		

Which of the following figures [POINT ALTERNATIVES] can be folded/assembled like the star figure again?



OPCIÓN A

OPCIÓN B

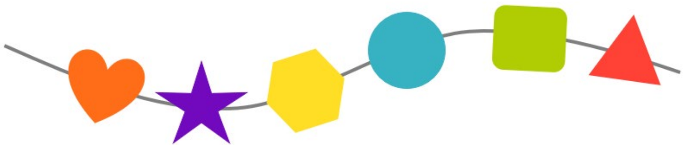


OPCIÓN C

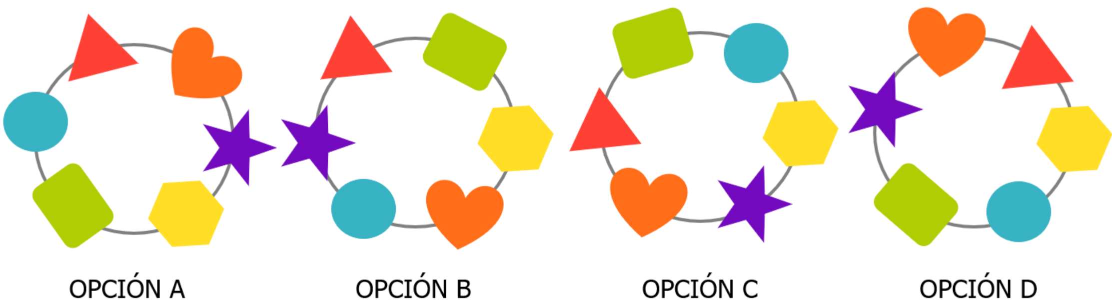
Correct answer: B

Task 11: Fix the bracelet

“Look, this was Mercedes' favorite bracelet, but now it's broken and looks like this” [POINT TO THE BRACELET]



“Which of the following four bracelets shows what Mercedes' bracelet looked like before it broke?” [POINT ALTERNATIVES]

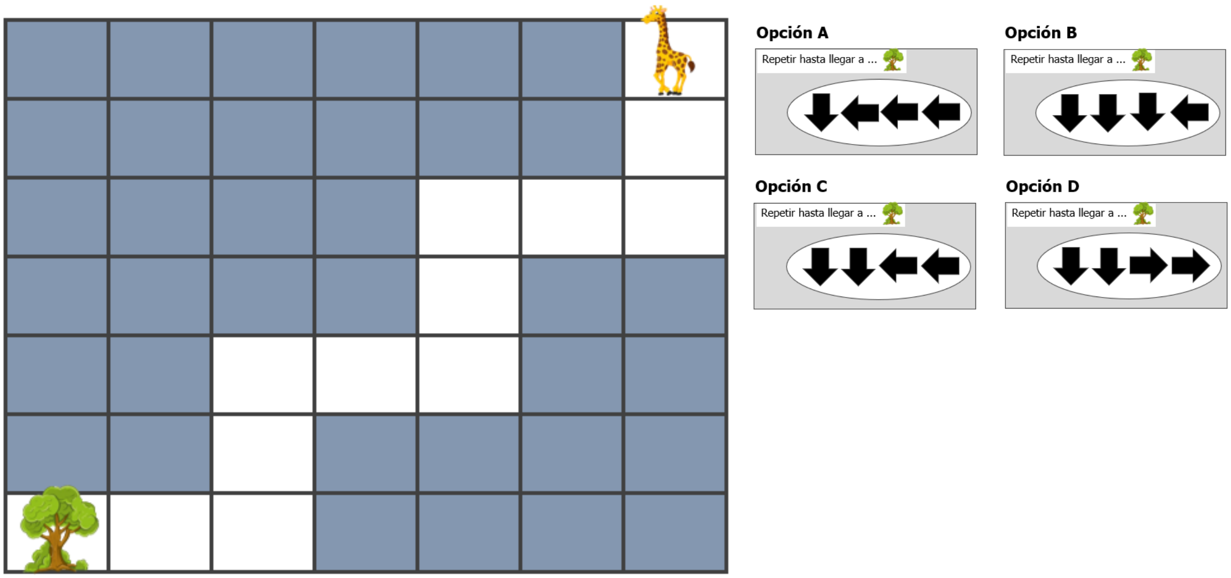


Correct answer: C

Teacher's CT test tasks

Task 1: Way home 1

In order for the giraffe to feed, it needs to reach the tree along the indicated path (white squares). What instructions should it follow?

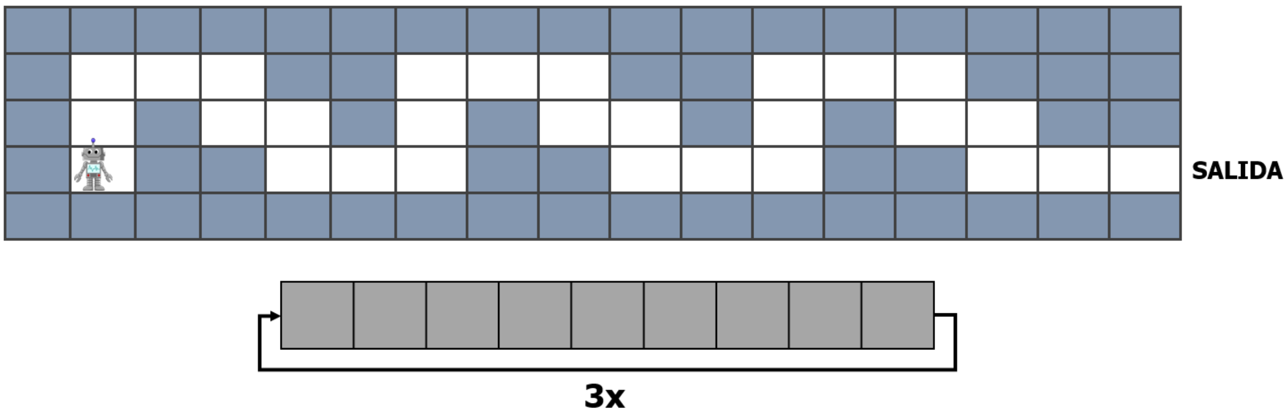


Note: The order of the arrows in the answer alternatives is from left to right. Please consider that order to answer the question.

Correct answer: C

Task 2: Trapped robot

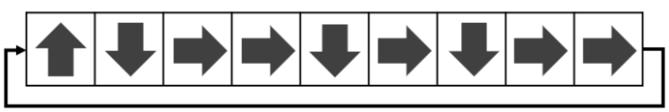
Help the robot get out of the maze. The robot will repeat the sequence of steps or instructions 3 times



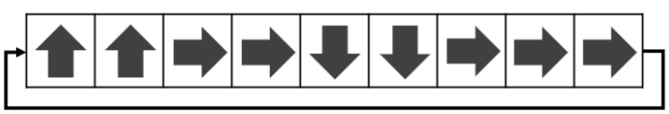
Question:

Which of the following alternatives represents the instructions that the robot must follow THREE times:

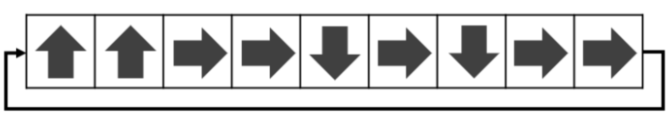
Note: The order of the arrows in the answer alternatives is from left to right. Please consider that order to answer the question.



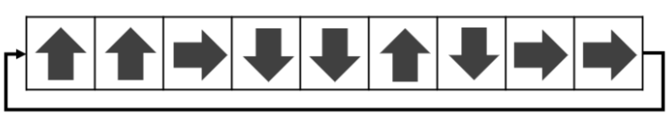
OPCIÓN A



OPCIÓN B



OPCIÓN C

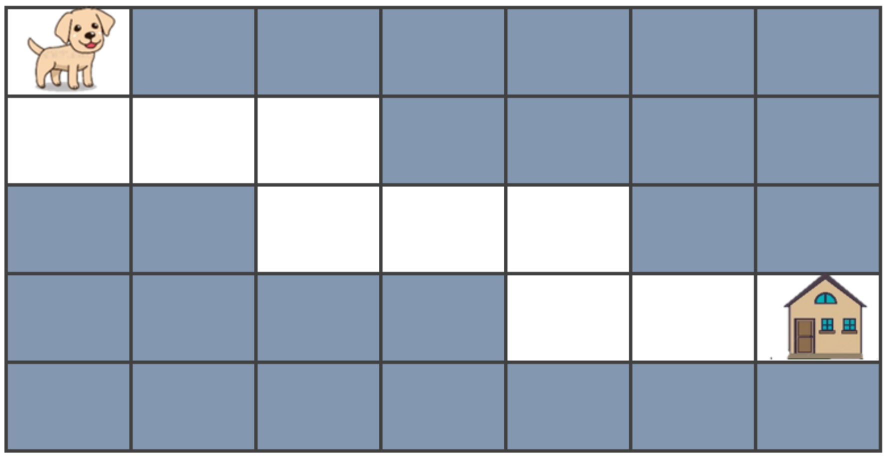


OPCIÓN D

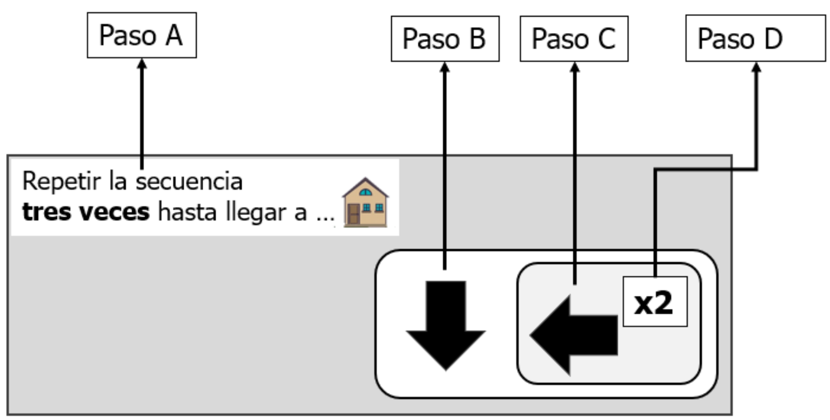
Correct answer: C

Task 3: Way home 2

In order for the dog to get to the house along the indicated path (blank squares), in which step of the following sequence of instructions is there an **error**?



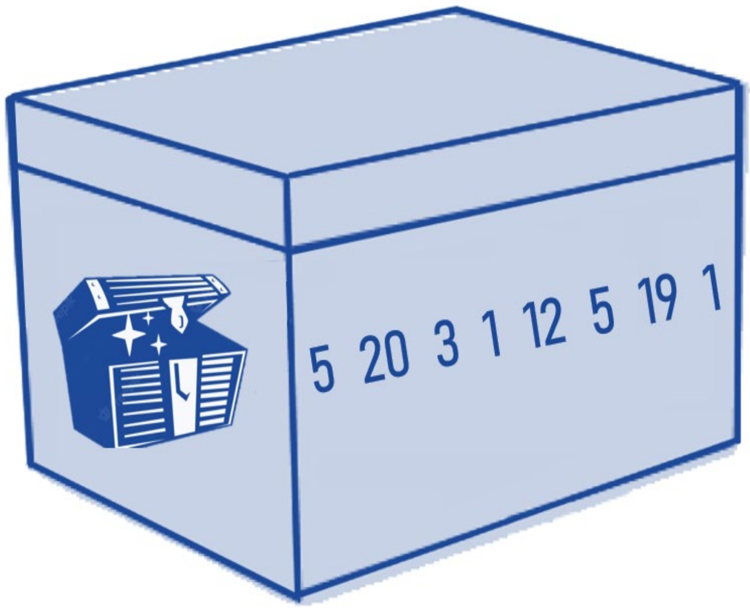
Sequence:



Correct answer: C

Task 4: Magic box

It takes a magic word to open a box. This secret code maps each letter of the alphabet to a unique number. The magic word code is written on the outside of the box. What is the magic word?



Alternatives:

a) estrella
b) elefante
c) escalera (correct answer)
d) equipaje