Exploring the role of floor robots in enhancing computational thinking skills and mental rotation in second and third graders

Explorar o papel dos robôs de chão na melhoria das capacidades de pensamento computacional e rotação mental em alunos do segundo e terceiro ano

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Abstract. The present study investigates the impact of using floor robots as educational tools to enhance computational thinking and mental rotation skills among second and third graders. In order to find out whether floor robots have a positive effect on improving students' computational thinking and mental rotation abilities, a pre-experimental study has been carried out. Specifically, 25 second graders and 25 third graders took part in the experiment. The intervention tasks were designed from a lower to a higher degree of complexity. Three areas were assessed: students' development of their computational thinking skills, students' development of their mental rotation abilities, and potential gender differences in these abilities. After analysing the three specific objectives and conducting tests both before and after the intervention, it was concluded that the use of floor robots improves students' computational thinking and mental rotation skills, regardless of students' gender.
Keywords: computational thinking; mental rotation; floor robots; primary school; gender differences.

Resumo. O presente estudo investiga o impacto da utilização de robôs de chão como ferramentas educativas para melhorar o pensamento computacional e as competências de rotação mental em alunos do segundo e terceiro ano. Para descobrir se os robôs de chão têm um efeito positivo na

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melhoria do pensamento computacional e das capacidades de rotação mental dos alunos, foi realizado um estudo pré-experimental. Especificamente, participaram no estudo 25 alunos do segundo ano e 25 alunos do terceiro ano. As tarefas de intervenção foram desenhadas de um menor para um maior grau de complexidade. Foram avaliadas três áreas: o desenvolvimento dos alunos nas suas competências de pensamento computacional, o desenvolvimento dos alunos nas suas capacidades de rotação mental e potenciais diferenças de género nestas capacidades. Após análise dos três objetivos específicos e realização de testes antes e depois da intervenção, concluiu-se que a utilização de robôs de chão melhora o pensamento computacional e as capacidades de rotação mental dos alunos, independentemente do género dos alunos.
Palavras-chave: pensamento computacional; rotação mental; robôs de chão; ensino primário; diferenças de género.

Introduction and justification

In the current digital era, the integration of technology in education has become a crucial aspect for the development of computational skills in primary education students. Since computer science and technology are essential parts of our daily lives, it is crucial to provide children with the necessary tools to develop their computational thinking (CT) skills. Hence, within this context, programmable robots have emerged as promising tools to enhance the understanding and application of computational concepts in young learners.

The choice of this topic for the present study is grounded in several fundamental reasons. Firstly, in an increasingly digitalized world, it is crucial to equip students from an early age with solid computational skills to prepare them for future challenges. Floor robots offer a practical and engaging way to introduce computational concepts, such as programming logic and algorithmic problem-solving, in an accessible and enjoyable manner for primary education students (Bakala et al., 2023).

Secondly, this research also aims to analyse if the use of floor robots improves students' mental rotation (MR). Città et al. (2019) reported that the abilities required to program a floor robot's movements include bodily movements that link cognitive functions with spatial and environmental knowledge. In relation to STEAM, spatial skills, including MR, are strong predictors of mathematics achievement (Bruce & Hawes, 2015). Given its importance in spatial reasoning skills, which are necessary for comprehending and learning mathematical concepts, MR plays a critical role in mathematics (Hertanti et al., 2019). Thus, adding MR activities to classrooms can contribute to the improvement of young children's spatial skills, bridging the gap between cognitive science and mathematics education and highlighting the significance of MR in the early stages of mathematical development.

Finally, it is also important to consider whether students' CT skills and their MR varies depending on students' gender. One major problem impeding inclusivity and diverse perspectives in the computer science education is the gender gap in CT skills (Niousha et al., 2022). Therefore, teachers may foster more inclusive learning environments and draw students of all genders into computer science by identifying and addressing these gender disparities in CT, encouraging gender parity in the teaching of technology. Moreover, concerning MR, a meta-analysis conducted by Masters and Sanders (1993) found that males consistently outperform females in MR tasks. Their analysis, which focused on adolescents and young adults, concluded that the magnitude of this gender difference has remained stable over time, challenging the general assumption that the gender gap in spatial ability was diminishing. More recently, Lauer et al. (2019) conducted a meta-analytic review of 303 effect sizes involving over 30,000 children and adolescents. Their findings showed that gender differences in MR emerge during childhood and increase with age —with males typically performing better in MR tasks—, reaching a moderate effect size in adolescence. Together, these studies underscore the persistence of gender differences in MR across time and developmental stages. In this context, it is particularly important to be able to create inclusive teaching sessions that equally develop the skills of both boys and girls, or that, if necessary, reduce pre-existing gender gaps.

To sum up, this work will address the significant question whether floor robots can enhance computational skills and MR in primary education students, specifically, in second and third-grade students, also considering a gender perspective. This research will not only contribute to the existing body of knowledge in the field of technology education but also provide practical insights and recommendations for educators to allow students of both genders develop their CT skills and their MR. Hence, the findings of this study are expected to provide valuable insights for enhancing the teaching and development of computational and spatial skills in classrooms.

Literature review

Computational thinking

According to Wing (2006), CT is a process that makes use of core computer science ideas to solve problems, build systems, and comprehend human behaviour. In accordance with this definition, CT not only involves technical knowledge of programming but also the ability to frame problems in ways that can be addressed with algorithmic solutions. Indeed, Wing (2006) suggested that CT ought to be regarded as a fundamental ability for all tasks requiring human analytical capacity, not only computer programming procedures.

With the advancement of technology, it has become increasingly important to introduce computing concepts in the early years of basic education. CT teaches people how to use informatics concepts to think through problem solving. Thus, CT is a fundamental concept in K–12 education because of its importance in information processing and problem-solving (Raimundo & dos Santos, 2023). Consequently, incorporating CT into the classroom helps students develop their logical reasoning, problem-solving abilities, and adaptability, setting them up for success in a world that is becoming more and more reliant on technology.

Considering gender, previous studies have shown mixed results regarding differences in CT skills. While some research highlights disparities favouring one gender, others find no significant differences, particularly when interventions are carefully designed (Bati, 2022; Lin & Wong, 2024). For instance, Angeli and Georgiou (2023) found that scaffolding methods can significantly influence the development of CT skills in young children, with boys generally benefiting more from kinaesthetic, spatially oriented tasks, and girls from collaborative strategies. Similarly, Angeli and Valanides (2020) demonstrated that young boys and girls can achieve significant learning gains when scaffolding strategies are tailored to their needs, highlighting the importance of designing gender-sensitive interventions. Together, these findings underscore the necessity of carefully structured and adaptable scaffolding strategies to promote equity in CT education.

Mental rotation

Shepard and Metzler (1971) defined MR as the capacity to mentally rotate two or three-dimensional objects. According to these authors, MR is often defined as a shape-matching task where participants must first imagine one element rotated into the same orientation as the other to make the necessary comparison between two elements.

An established research paradigm for analysing the cognitive processes involved in spatial thinking is the MR task. Indeed, MR is one subskill of spatial ability (González-Calero et al., 2019). It has been proved that practicing MR enhances spatial skills, especially when comparing and rotating objects. This improves performance on spatial tasks like perspective-taking and object rotation (Enge et al., 2023). What is more, spatial experiences are at the same time important for improving MR abilities, highlighting the significance of practice and exposure to spatial tasks for the development of MR skills. Therefore, there is a complex mutual relationship between MR and spatial abilities, demonstrating how MR exercises can provide information about cognitive processes as well as individual variations in spatial processing and thinking.

If we talk about the advantages of MR, this skill is necessary for mathematics itself, not just because of curriculum demand. Studies have shown a positive correlation between MR abilities and arithmetic performance, particularly in newly acquired arithmetic material, indicating that MR skills are necessary for understanding geometry, arithmetic, and other mathematical operations (Georges et al., 2019). Additionally, MR helps students prepare for careers in graphic design, computer programming, and architecture. Moreover, MR exercises have also been shown to enhance short-term memory, decrease response times, improve psychophysiological performance, and increase brain function (Hertanti et al., 2019).

Finally, regarding gender, numerous studies have been conducted in a variety of contexts to examine gender differences in MR tasks. According to Ebert et al. (2024), examining gender stereotypes is a pertinent way to comprehend how spatial ability develops and how sex differences occur in the field. In fact, the results of their study concluded that children in preschool had clear gender stereotypes about spatial ability, associating it with boys instead of girls, which could explain the gender difference in spatial ability that favours men. More specifically, in MR, gender differences are more pronounced (González-Calero et al., 2019). Actually, one of the biggest sex differences in the cognitive literature has been found to result from the ability to mentally rotate an object (Linn & Petersen, 1985). Gender differences in performance can be influenced by various factors, including task characteristics, the use of rotational materials, and cognitive strategies used during MR tasks (Zawadzka, 2022). Furthermore, the complex interaction between cognitive abilities and gender differences in spatial tasks is highlighted by the ways in which individual beliefs about spatial abilities, such as growth mindset, interact with MR abilities to impact the acquisition of spatial knowledge (Miola et al., 2023).

Educational robotics

The use of robots in educational environments to improve learning outcomes is known as educational robotics (ER). By encouraging active learning and relieving the strain of conventional teaching methods, the use of robots in education has improved learning and made it more dynamic and engaging for both teachers and students (Sheoran & Chaudhary, 2023). ER has gained popularity during the last ten years. Robots are being used in a variety of ways to teach and learn different subjects at different educational levels (Diago et al., 2022). ER has been successfully incorporated into curricula to promote students' interest in technology, creativity, and problem-solving abilities at all levels of education (D'Abreu & Condori, 2017). The goal of introducing ER into school settings is to give kids the chance to conduct research, find information, and use it in a real-world setting (Somyürek, 2015). Though they face obstacles like gender inequality and technological constraints, educational robots have a lot of applications in STEM education, language learning, and special education (Pei & Nie, 2018).

In relation to computational thinking

CT has gained acceptance in the research community as a crucial ability to cultivate in educational and professional environments. The use of programmable robots as educational tools offers a unique opportunity for interactive and experiential learning, which can enhance the development of CT effectively (Resnick, 2017). Numerous scholars contend that the development of CT ought to occur within the framework of robotics and programming at every educational level, beginning with early childhood education (Angeli & Georgiou, 2023).

Particularly in K–12 education, ER is essential for developing students' CT abilities. ER-based interventions can help young learners begin to develop CT (Bers, 2008). Children actively interact with powerful concepts from robotics and computer science, including the fundamentals of CT, when using an ER approach. Studies highlight how important it is to integrate ER into the curriculum in order to improve students' CT, coding, and problem-solving skills (Pérez-Suay et al., 2023). Research have demonstrated that introducing young learners to programmable robots for problem-solving tasks based on mathematical concepts can effectively foster CT (Drakatos & Stompou, 2023). By incorporating ER into standard classroom environments, teachers can give students stimulating chances to improve their CT skills and get ready for challenges in the STEM fields in the future.

Furthermore, ER collaborative learning environment and the adaptability of robots both can greatly aid in the development of CT skills, allowing students to enhance not only their algorithmic thinking and programming competence, but also their teamwork skills (Ching & Hsu, 2023).

In relation to mental rotation

It has been proved that ER can improve MR skills, especially in younger students. Research has shown that, when compared to conventional methods, robotics-based instruction can improve MR skills more than traditional methods, favouring males (González-Calero et al., 2019). Moreover, ER helps students develop their spatial skills since it introduces them to basic geometric and spatial concepts that are investigated when programming a robot's movements, such as space perception, space conceptualization, and general spatial abilities, particularly concerning MR skills. For instance, when programming these robots, students give them directions such as turning to the right or to the left, thus, putting into practice their MR abilities.

Robotics-based instruction holds great promise for improving spatial abilities in educational settings. Innovative models linked to ER can have a major influence on cognitive development, especially with regards to spatial skills like MR (González-Calero et al., 2019; Julià & Antolì, 2018), particularly in males (Seepanomwan et al., 2013). In addition to increasing performance and allowing students to practice their MR, ER-based interventions can improve user perceptions and engagement (Sharma et al., 2019).

Methodology

Participants

The present study has been carried out in a single-track school of Early Childhood Education and Primary Education in an urban area of Spain, during the school year 2023/2024. In the study, 50 students aged 7-9 years old participated. They were distributed as follows: 25 students (13 boys and 12 girls) from second grade of Primary Education and another 25 students (13 boys and 12 girls) from third grade of Primary Education. Before starting the research, each of the children's parents was asked to sign a consent form for their children to participate in the study. This study was part of a project approved by both the Ethics Committee on Social Research of the University of Castilla-La Mancha and the Regional Administration.

Design

This study is a pre-experimental design (one-group pre-test-post-test), since there is no control group. The school where we conducted our research did not allow us to make another kind of design for our study, as it is a single-track school and the number of students in each grade was low. According to Ary et al. (2009), a pre-experimental design provides minimal or non-existent control over unrelated factors. Although when applying pre-experimental designs, the researcher should consider certain limitations such as non-random sampling, sensitization to testing, and statistical regression (Karp & Fry, 2021), pre-experimental design is quite important in research. For instance, it makes it possible to evaluate interventions by contrasting the results obtained prior to and following the intervention (Ma & Wang, 2023), as well as determine how interventions affect variables, enabling quick evaluation of results and directed analysis (Stratton, 2019). Thus, researchers can assess interventions more successfully and increase the validity of their studies by recognizing the possible drawbacks of pre-experimental designs and taking advantage of their strengths.

Our study spanned six weeks. The first week was dedicated to the pre-test. The subsequent four weeks were allocated to programming sessions involving robots, with tasks of increasing complexity each week. In the final week, we conducted the post-test.

In the Instruments section, we will discuss the tests used to measure the students' spatial reasoning and computational thinking skills. To assess spatial reasoning, we used the 2D Mental Rotation Test (2D MRT) and the 3D Mental Rotation Test (3D MRT). For evaluating computational thinking skills, we employed the Beginners Computational Thinking Test (BCTt).

Procedure

All the students completed both the pre-test and the post-test individually, but regarding the development of the sessions, students programmed the robots in pairs and trios. The pre-test and post-test were carried out in the students' classrooms, but the programming sessions with the robots took place in the school gym, since it was a large classroom with enough space.

As it has been mentioned above, the total number of students was 50, and since there were 25 in each class, we grouped them into 22 pairs and 2 trios. In order to save time during the sessions, 2 pairs programmed the robots simultaneously, so that in the school gym there were 4 students (or 5 students, if it involved the trios) programming their corresponding robots at the same time, but placing each pair or trio in different locations of this classroom, to ensure they could not observe the programming activities of the other groups.

Materials: Bee-Bot and grid board

To carry out the intervention program of our research, we employed the educational robot Bee-Bot. Bee-Bot is used to introduce students to CT and provide a foundation for teaching science, math, language, and literacy in educational settings (Osorio & Caballa, 2023). This robot, which is a highly recognized floor robot utilized in preschool and primary education (Brennan & Resnick, 2012), is a robotic bee designed to help students learn sequences, estimation, problem solving, and logical thinking. It has arrow keys that can be used to enter commands to move the Bee-Bot forward, backward, left, and right by 90º (Seckel et al., 2023). By clicking the green GO button after entering the desired command sequence, the Bee-Bot begins traveling along the designated path. Bee-Bot can perform up to 40 movements (see Figure 1).

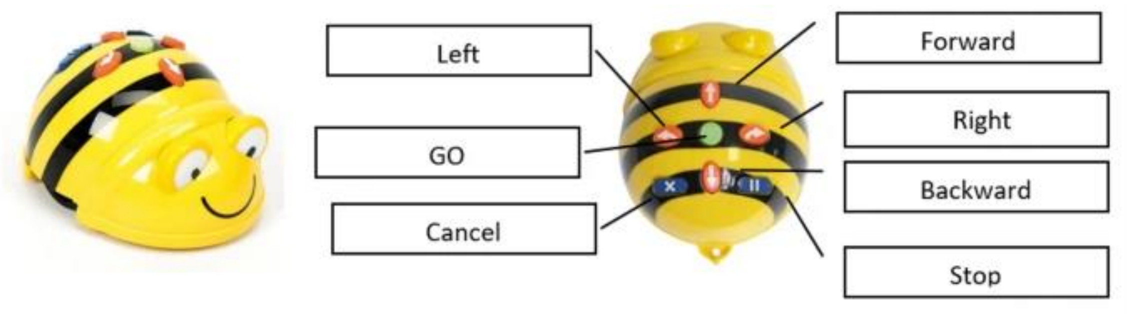

Figure 1. Programming keys of Bee-Bot (Seckel et al., 2023)

To program the robots, students must create an action plan that follows the right path for which they have manipulative direction cards available before entering the chosen codes into the robot. Once students have designed the desired sequence using the direction cards (see Figure 2), they must press the direction buttons on the robot so that it can execute the programmed route.

Card	Instruction
	Go forward
	Go backward
	Turn to the right
	Turn to the left
	Execute the sequence

Figure 2. Direction cards (Diago et al., 2022)

We used two 4x5 grid boards (one for each robot to move in). Each square of the grid board was 15x15, since the robot can move forward or backward only 15 cm. Furthermore, to show students the sequence they had to program in each task following the design of the sessions, we stuck a red adhesive tape to the grid board, so that the robots could follow the established routes and get to the flower (see Figure 3).

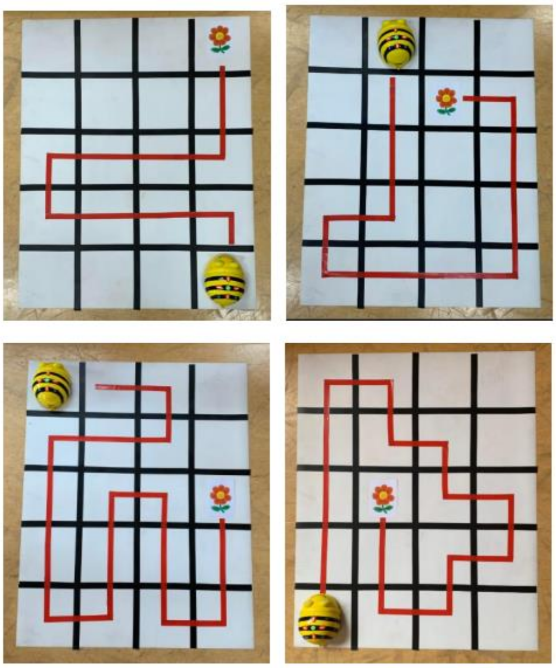

Figure 3. Examples of routes of the programming sessions

Programming sessions

Students programmed the robots during 4 sessions. The total number of tasks they had to complete was 16 (4 tasks per session). As mentioned in the literature review section, it is quite important to apply scaffolding methods to allow students develop their CT skills in a progressive way, so the level of complexity of the tasks we designed was increasing as the sessions progressed. Therefore, in the first sessions the tasks included few turns, while in the last sessions the number of both left and right turns increased considerably. All the sessions were aimed to improve students' CT skills as well as their MR.

In the first session, we explained to all students how the robot worked as well as the direction cards they must use to program the robots. The instructions were clear from the very beginning: firstly, they had to decide which direction cards they had to use so that they could program the sequence the robot was going to execute in each task and then they had to press the directions buttons on the robot so that it could perform the programmed sequence. Students were allowed 3 attempts to complete each task of the sessions and if they did not manage to complete the tasks, they moved on to the next one. As students were grouped in pairs and trios, they worked together to program the robots, improving their problem-solving skills in a cooperative way.

Table 1. Summary of tasks of each session

Task	Session	Number of steps	Number of turns	Mirror position
1	1st	4	0	No
2	1st	5	1	No
3	1st	6	2	Yes
4	1st	9	2	Yes
5	2nd	10	4	No
6	2nd	11	4	No
7	2nd	14	4	Yes
8	2nd	12	5	Yes
9	3rd	15	6	No
10	3rd	18	7	Yes
11	3rd	21	7	No
12	3rd	26	9	Yes
13	4th	28	9	Yes
14	4th	24	10	Yes
15	4th	25	10	Yes
16	4th	27	10	Yes

As it can be observed in Table 1, the number of steps and turns increases progressively as the sessions and the tasks go by. It should be noted that there are some tasks that have fewer steps than the following ones that follow them, but in any case, we gave priority to the number of turns than steps.

It is also worth mentioning that when we talk about "mirror position", we mean that at certain point in the task, the robot goes in the opposite direction to the children's starting position, which sometimes hinders children's MR, as they are often confused with right and left turns.

Instruments

In order to select the appropriate 2D and 3D MR instruments for our research, we conducted an extensive review of over 200 articles. The review mainly focused on identifying instruments to measure MR skills in primary education settings, providing an overview of the techniques, tools, and instruments used for MR assessment in young learners.

The literature search and analysis took place between November 2023 and February 2024. Two scholarly databases were queried: Web of Science and Scopus. Additionally, Google Scholar was used to locate grey literature. After thorough research, we selected the instruments described below for our study.

2D Mental Rotation Test

To evaluate students' 2D MR ability, we employed a 10-item test based on the research conducted by Collins and Kimura (1997). Each of the test's items consists of three two-dimensional stimuli (see Figure 4 for an item example). Students must match one of the red stimuli with the grey stimulus at the top, so they must visualize carefully the grey stimulus to match its corresponding rotated figure. Following the established protocol of action of the test, we let students a total time of 5 minutes for doing it (30 seconds per item, since there are 10 items). The scoring system of this test is 1 point for each correct answer, so the total scoring of the test is 10.

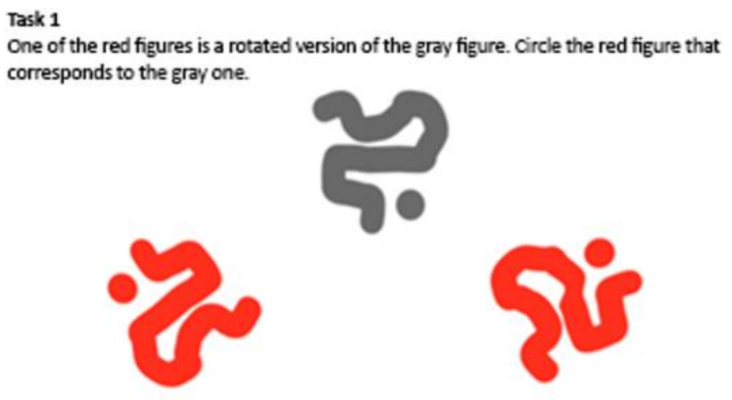

Figure 4. 2D Mental Rotation Test item example (Collins & Kimura,1997)

3D Mental Rotation Test

We selected the Revised Vandenberg and Kuse Mental Rotations Tests by Peters et al. (1995) as an instrument of 3D MR for our research. According to Peters et al. (1995), there are four distinct versions of the test available, all of them based on the Shepard figures (Shepard & Metzler, 1971) that served as the foundation for the original Vandenberg and Kuse (1978) Mental Rotations Test figures: MRT-A, MRT-B, MRT-C and MRT-D (from least to greatest complexity). The version of the MRT test we have used for our research is the first one, the MRT-A, the standard set in which the stimulus figures were redrawn from the original Vandenberg and Kuse set, as it was most suitable for the skill level of our primary education participants.

The Vanderberg and Kuse test consists of 24 problems, in which four stimulus figures are displayed on the right of each problem, with the target figure displayed on the left. Two of these stimulus figures are rotated by the target figure, and two of the stimulus figures are unmatchable with the target figure (see Figure 5 for an item example).

As for the scoring system, a single point is awarded when both the stimulus and target figures are recognized accurately. For a single correct response, there is no credit awarded. Therefore, a total of 24 is the highest possible score on the test using this system. Although in the instructions of the test it is stated that students must have 3 minutes to do both pages 1 and 2 and other 3 minutes to do pages 3 and 4, with a 2-minute break in between, it is also established that the researcher could let students do each pair of pages in 4 minutes (that is adding one minute more), if necessary. Thus, taking into account the age of our students, we considered it necessary to let them 4 minutes for completing each pair of pages.

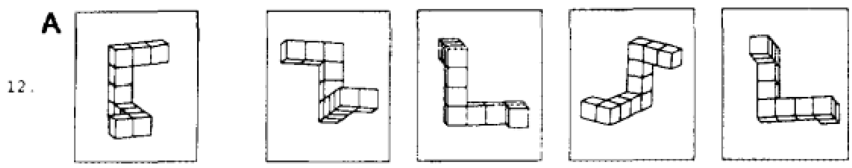

Figure 5. 3D Mental Rotation test item example (Peters et al., 1995)

Beginners Computational Thinking Test (BCTt)

Román-González (2015) developed the Computational Thinking Test (CTt) for secondary school students and then, Zapata-Cáceres et al. (2020), based on the CTt, designed the Beginners Computational Thinking Test (BCTt) for primary school students. These authors determined that BCTt can be used with primary school students, especially those in the first grades (5 to 10 years old). For this reason, we chose this test as our tool to measure students' CT skills in our research.

The original test consists of 25 items divided into 6 blocks, each addressing a different type of computational concept (see Figure 6). For our study, we adapted the test by including only the first 11 items instead of the full 25. These 11 items correspond to the first 2 blocks: the first block contains items related to sequences, and the second block focuses on simple loops. We selected these 2 blocks because they directly relate to the programming sessions in our research. Each item presents 4 options (A-D), with only one correct answer.

Item	Interface	Size	Obstacles	Pick-ups	Computational concept					
						Loops		*Conditionals*		
					1.Sequences	*2.Simple*	*3.Nested*	*4.If-Then*	*5.If-Then-Else*	*6.While*
1	Maze	Small			x					
2	Canvas		-	-	x					
3	Maze	Small	x		x					
4	Maze	Small	x	x	x					
5	Maze	Large	x	x	x					
6	Canvas		-	-	x					
7	Maze	Small				x				
8	Maze	Small				x				
9	Maze	Small	x			x				
10	Maze	Large				x				
11	Maze	Large		x		x				

Figure 6. Computational concepts for each BCTt item. Adapted from Zapata-Cáceres et al. (2020)

According to the BCTt action and evaluation protocol, the test should be administered to primary education students within an average time of 45-60 minutes, ideally fitting within a class session. Since our test included fewer items, we evaluated the students in 15-25 minutes. The tests were administered in printed paper format, and each student received a copy.

Statistical analysis

To examine statistically significant differences in the dependent variables (CT, 2D MR, 3D MR) across grade levels in both the pretest and post-test, an independent t-test will be conducted. To assess potential differences in these variables before and after the intervention, a paired t-test will be used. Effect sizes will be reported using Cohen's d. If the assumptions for parametric tests are not met, the Mann-Whitney U test and the Wilcoxon signed-rank test (W) will be employed as non-parametric alternatives to the independent and paired t-tests, respectively. In such cases, effect sizes will be calculated using Rosenthal's r.

Results

The results obtained by all students both in the pre-test and post-test for each of the areas are displayed in this section. The results pertaining to CT skills are first shown and then, the results related to MR. Finally, we examine the results for both areas, while accounting for the students' gender.

Computational thinking

Table 2 displays the test's average score on a scale from 0 to 11 for CT-related problem-solving abilities. The standard deviation of each measure is also provided in parenthesis. While descriptively, the CT level of third graders prior to the intervention appears higher than that of second graders, a Mann-Whitney test did not identify these differences as statistically significant ($U = 302$, $p = .84$, $r_s = .03$). The same situation occurs in relation to the post-test ($U = 287$, $p = .57$, $r_s = .08$). In the comparison between pretest and post-test, a statistically significant increase is observed after the intervention ($W = 40$, $p < .001$), which can also be classified as having a large effect ($r_s = .87$). The effect is large for second graders ($W = 3$, $p < .001$, $r_s = .96$) and third graders ($W = 18$, $p = .003$, $r_s = .79$).

Table 2. CT average results

Grade	n	Pre-test$_{CT}$	Post-test$_{CT}$
Year 2	25	7.48 (3.85)	9.80 (2.74)
Year 3	25	8.00 (3.20)	10.2 (2.25)

Mental rotation

As shown in Table 3, regarding 2D MR, in the pre-test there were no statistically significant differences between second and third graders ($U = 258$, $p = .28$, $r_s = .18$). Similarly, no differences were found in the post-test ($U = 307$, $p = .92$, $r_s = .02$). Overall, the intervention was found to be effective in improving students' 2D MR skills ($W = 70.5$, $p < .001$, $r_s = .844$). The benefit was similar in both age groups, both in second ($W = 19$, $p < .001$, $r_s = .86$) and third grade ($W = 18$, $p = .002$, $r_s = .81$). The effect size can be considered large, which indicates the impact of the intervention.

Table 3. 2D and 3D MR test average results

Grade	n	Pre-test$_{2D}$	Post-test$_{2D}$	Pre-test$_{3D}$	Post-test$_{3D}$
Year 2	25	6.60 (1.85)	8.48 (1.23)	6.32 (3.42)	8.36 (3.75)
Year 3	25	6.96 (2.39)	8.52 (1.08)	4.44 (2.84)	9.56 (3.88)

Next, we proceed to analyse 3D MR skills. As before, Table 3 shows the descriptive statistics for each grade level and test, showing a higher initial level of second graders compared to third graders. These differences are statistically significant and have a small effect size (U = 212, p = .049, r_s = -.32). As a result of the intervention, this gap disappeared in the post-test (U = 242, p = .17, r_s = .23). The fact that in the post-test, at a descriptive level, the results are slightly higher for third graders, reveals that the intervention has been highly productive for third graders (W = 1.00, p < .001, r_s = .994), to a greater extent than for second graders (W = 12.00, p < .001, r_s = .86). However, the effect can be considered large in both cases.

Gender

Finally, we evaluated the existence of potential gender gaps prior to the intervention and the effect of the intervention in maintaining equitable outcomes across genders. We compared the results of girls and boys for each variable and grade level, incorporating both descriptive and inferential analyses (Table 4). For second-grade students, inferential analyses using the Mann-Whitney U test did not detect significant gender differences in any of the variables, either before or after the intervention. Specifically, no significant differences were observed in the pretest scores for 2D MR (U = 68.5, p = .619), 3D MR (U = 64.5, p = .475), or CT (U = 68.0, p = .599). Similarly, post-test comparisons revealed no significant differences for 2D MR (U = 66.0, p = .490), 3D MR (U = 73.5, p = .826), or CT (U = 61.5, p = .322). For third-grade students, inferential analyses similarly indicated no significant gender differences in the variables studied. Pretest scores for 2D MR (U = 59.0, p = .303), 3D MR (U = 53.5, p = .187), and CT (U = 66.5, p = .545) showed no statistically significant differences between boys and girls. Post-test analyses also revealed no significant gender differences for 2D MR (U = 72.0, p = .753), 3D MR (U = 61.0, p = .366), or CT (U = 77.0, p = .974). These findings underscore that the intervention was equally productive for both boys and girls.

Although some initial differences were observed at the descriptive level (e.g., higher CT levels in second-grade boys compared to girls), the inferential analyses confirmed that these differences were not statistically significant. Furthermore, the intervention demonstrated consistent effectiveness across genders, avoiding the emergence of any gender gaps and supporting equitable learning outcomes for all students.

Table 4. Tests average results in relation to gender

Grade	n	Gender	Pre-test$_{CT}$	Post-test$_{CT}$	Pre-test$_{2D}$	Post-test$_{2D}$	Pre-test$_{3D}$	Post-test$_{3D}$
Year 2	13	Boys	8.15 (3.21)	9.92 (3.01)	6.31 (2.02)	8.54 (1.39)	6.15 (3.36)	8.54 (4.61)
	12	Girls	6.75 (4.47)	9.67 (2.53)	6.92 (1.68)	8.42 (1.08)	6.50 (3.63)	8.17 (2.72)
Year 3	13	Boys	7.54 (3.62)	9.77 (3.06)	6.31 (2.98)	8.54 (1.20)	3.62 (2.87)	9.15 (2.08)
	12	Girls	8.50 (2.75)	10.6 (0.67)	7.67 (1.68)	8.50 (1.00)	5.33 (2.64)	10.0 (5.27)

Analysis and discussion of results

Focusing on the computational area, in Table 2 we can observe that, for both second and third graders, the average scores in CT on the pretest were higher than 7 out of 11, which indicates a competent initial level in the CT area. These initial high results may be because, in the school where the research was conducted, some students attended robotics lessons and thus, they had a relatively solid foundation in robotics. Nevertheless, comparing pre-test and post-test results, we can see a significant improvement in the CT skills of children in both grades. In this regard, it should be emphasized that, although the initial level was relatively high in both grades, the gains can be considered substantial.

Like in the studies conducted by Diago et al. (2022), which showed statistically significant learning gains in the children's CT abilities between the first and last assessments, our results demonstrate the potential of robotics activities to foster CT skills. Furthermore, as highlighted by Angeli and Valanides (2020), scaffolding strategies tailored to the needs of learners can amplify these gains and reduce gender gaps. Additionally, these findings align with those of Lin and Wong (2024) and Bati (2022), who emphasized that well-designed robotics interventions are effective in promoting CT development in young learners. Using programmable floor robots, like Bee-Bot, in robotics activities thus proves to be a useful strategy for promoting young children's CT.

Concerning the analysis of MR, we will first describe the results obtained by students in the 2D Mental Rotation Test, followed by the results from the 3D Mental Rotation Test.

On the one hand, as shown in Table 3, it is worth mentioning that since the maximum total score of the 2D Mental Rotation Test is 10, the initial level of students' 2D MR can be considered good, with average scores ranging between 6.6 and 6.96. We can observe that there are no significant differences between second and third graders' Pre-test$_{2D}$, since the averages vary very little. What is more, the post-test results show even less difference between the two grades compared to the pre-test. However, we observed a considerable increase in overall students' 2D MR skills after the intervention, with an average score of around 8.5 for both grades, indicating a final high level of 2D MR abilities. Moreover, as occurred with the CT tests, third graders scored higher than second graders.

On the other hand, as shown in Table 3, second graders have a higher initial level of 3D MR compared to third graders. Notwithstanding, considering the total score of the test is 24, the scores obtained in the Pre-test$_{3D}$ are very low in general, not only for third grade students but also for second graders. This suggests that most students had underdeveloped 3D MR skills at the beginning of the intervention. As previously mentioned, third graders' results are marginally higher in the post-test, which indicates that the intervention was more beneficial for them than for second graders. In both scenarios, the effect of the intervention can be regarded as substantial, since all students increased their 3D MR abilities. Nevertheless, the average of Post-test$_{3D}$ results remain low.

It is worth noting that, during the 3D MR pre-test, some third graders appeared less focused compared to their second-grade counterparts. This informal observation by the researchers suggests that variability in concentration levels may have influenced the initial performance of third graders in the 3D MR test. However, as no specific data were collected to quantify this behavior, its impact remains speculative. This highlights a limitation of the study, as additional measures to monitor and control such factors could provide deeper insights into initial differences in performance. Future research could explore the role of concentration and task engagement in spatial reasoning assessments to better understand these dynamics. Moreover, the instructions of the 3D mental rotation pre-test were so much difficult for students to understand than the 2D mental rotation pre-test, so this could explain why the scores obtained in the Pre-test$_{3D}$ were very low, both for second and third graders.

Finally, regarding gender, this type of collaborative instruction suggests that all students have similar learning experiences, fostering equitable outcomes without the emergence of gender gaps. Both girls and boys were engaged in the same types of activities. and the instruction produced a uniform effect regardless gender. In terms of CT, these results may be linked to the collaborative nature of the proposal, as previously found by Angeli and Valanides (2020). Concerning MR, unlike the findings by Lauer et al. (2019), which reported that gender differences in MR emerge in childhood and increase with age, our intervention proved equally effective across genders. These results suggest that targeted educational interventions can effectively improve spatial reasoning skills, highlighting their potential to promote gender equity in early educational contexts.

Conclusions

The main objective of our research was to investigate the impact of an intervention program with floor robots in relation to students' CT skills and MR, taking also into consideration gender differences. Our findings confirm that the use of floor robots significantly improved students' CT skills and their 2D and 3D MR abilities. Thus, the findings of this study highlight significant advancements in CT and MR skills among second and third graders after the intervention, confirming that the implementation of ER in the classroom has a substantial positive influence on children's CT and MR.

Overall, the intervention has proven to be highly effective in enhancing both CT and MR skills among the students, with third graders showing particularly notable progress. At the same time, the instruction has been appropriate to reduce initial gaps. This study underscores the potential benefits of integrating computational and spatial reasoning activities into early education curricula through ER. The results clearly demonstrate a significant improvement in students' CT and MR skills, supporting the effectiveness of the intervention despite its brevity. The results clearly demonstrate a significant improvement in students' CT and MR skills, supporting the effectiveness of the intervention despite its brevity. Furthermore, the analyses broken down by gender revealed that the benefits were equally significant for both girls and boys, with comparable gains observed in both CT and MR skills.

Therefore, this study demonstrates how a brief robotics-based intervention can significantly enhance specific mathematical skills and provide a solid foundation for future studies that could investigate the use of various technological tools, such as robot simulators.

As it has been mentioned throughout this work, CT has a lot of benefits for the development of students. Through systematic methods, data analysis, algorithms, abstraction, and information representation, CT improves problem-solving abilities (Isharyadi & Juandi, 2023). Moreover, CT enhances reasoning and creative thinking, which are crucial in mathematics for understanding and solving complex problems. Hence, by incorporating CT into the classroom, educators can give students the tools they need to succeed in a digital world while also encouraging creative and fulfilling learning opportunities.

Furthermore, concerning the benefits of MR, which is associated with learning, intelligence, and academic success (Mast & Gurtner, 2023), it has been demonstrated that practicing mental rotation improves spatial abilities, as they perform better on tasks requiring object rotation and perspective-taking (Enge et al., 2023). These spatial skills are vital in mathematics, where visualizing and manipulating shapes and objects are often required to understand geometric and algebraic concepts. MR also contributes to the general development of cognitive skills, and it is particularly important in STEM disciplines, facilitating the acquisition and application of complex concepts in these areas.

Therefore, CT and MR skills are essential for the holistic development of students, providing vital tools for problem solving, innovation, and academic success in mathematics and other multiple disciplines. For these reasons, integrating these abilities into education through ER is crucial to preparing students for the challenges of the modern world and to fostering deep and lasting learning.

However, though the implementation of ER in the classroom is very effective for enhancing CT and MR, ER can have certain limitations. Those problems include the high expense of supplying and maintaining robots, the dearth of robotics-trained and qualified teachers, the lack of methodological and educational support, and the absence of a well-defined systemic plan for incorporating robotics into curricula in schools (Drakatos & Stompou, 2023). Indeed, to effectively incorporate robotics into the curriculum, educators must possess specific knowledge and training in the field. Many teachers might not have the confidence or skills needed to teach robotics, which could result in an inadequate use of the technology or a reliance on outside experts.

Nevertheless, despite these barriers, the potential advantages of ER in strengthening problem-solving abilities and advancing STEM education highlight how critical it is to get past these obstacles to fully realize robotics' educational potential in classroom settings (Rovshenov et al., 2022).

While this study provides valuable insights, it is important to acknowledge certain limitations. The reduced sample size limits the generalizability of the findings. Additionally, the study's context, which involved participants from a specific school, may not fully represent broader populations. Finally, potential biases in the measurement of skills, such as variability in engagement levels during testing or differences in prior exposure to similar tasks, should be considered when interpreting the results.

Given the technological dependency of today's world, it is expected that, taking into consideration the results obtained in this study, curriculum designers and educators become more aware of the importance of including ER into Primary education classrooms, so that they take the appropriate measures to allow students develop their CT and MR skills in an engaging and dynamic manner. Additionally, the collaborative potential of ER activities can help bridge gender gaps, ensuring both boys and girls benefit equally from these learning experiences. Thus, to make sure that robotics activities meet learning objectives and standards, careful planning and thoughtful implementation are essential.

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