Education and Information Technologies (2025) 30:21079–21103
https://doi.org/10.1007/s10639-025-13589-3

Characterising computational and geometric thinking in pre-service Early Childhood Education teachers by playing with MatataLab

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Received: 4 December 2024 / Accepted: 17 April 2025 / Published online: 10 May 2025
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Abstract

This article aims to characterise geometric and computational thinking of future Early Childhood Education teachers through participating in a robotic problem-solving activity for 5-year-old pupils using MatataBot, MatataLab's educational robot. The study, carried out during academic year 2022–2023, involved 42 early childhood education students from a Spanish university. The methodology was divided into three phases: in the first, the participants familiarised themselves with the robot; in the second, they programmed the robot to represent basic geometric figures; and in the third, they reflected on their learning and on the geometric aspects identified. The data obtained in the last two phases (gathered from observations and videos recorded by the authors during the implementation, from the reports the different groups of students presented, and from the videos they recorded of the development of their activities) were analysed qualitatively using the Didactic-Mathematical Knowledge model from the Onto-semiotic Approach and the categories of common errors in programming. Pre-service teachers demonstrated conceptual gaps in geometric properties, leading to errors in programming representations. It is concluded that, although educational robots can enhance the understanding of geometry, it is essential to address the previous knowledge of teachers and prepare them in both mathematical knowledge and in the use of technological tools, fostering comprehensive training that enables the improvement of teaching in Early Childhood Education.

Keywords Computational thinking · Early geometric thinking · MatataLab's educational robot · Pre-service teachers' education · Early childhood education

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Extended author information available on the last page of the article

1 Introduction

To respond to the demands of today's society, such as achieving gender equality at work, including in science and technology-related professions, several countries have incorporated computational thinking (CT) in basic education curricula starting from an early age (Zapata-Ros, 2019). In Spain, the curriculum for the second cycle of Early Childhood Education (ECE) (children aged 3 to 6 years) integrates CT in the area of discovering and exploring the environment (Alsina, 2022; Ministry of Education and Vocational Training, 2022).

In order to comply with this regulation, it is essential to train teachers in promoting CT from ECE onwards (Ribeiro et al., 2011). An effective manner to develop CT is by means of educational robots (Blue-bot, Sphero Bot, MatataBot, etc.). In the past five years, research has been conducted on pedagogical practices and teachers'conceptions of CT development through robotics in the classroom (Casey et al., 2021; Tang et al., 2020), especially the use of educational robots at an early age (Papadakis, 2020; Seckel et al., 2021). MatataBot, MatataLab's educational robot, is designed to teach programming and CT to children aged 4 to 9. It stands out for its potential to enhance the understanding of geometric concepts, as it recognises positions, directions, and rotations. Furthermore, it supports problem-solving and the development of logical thinking by promoting optimal strategies to achieve objectives through trial and error (Didactia, s.f; Europa Press, 2017).

Despite much research on the development of CT in mathematical thinking (Seckel et al., 2022), the literature on the use of educational robots for the development of geometric thinking is scarce. Only a few hands-on learning experiments of geometric concepts through sensorimotor experiences (Stober et al., 2011) and of learning geometry through interaction with educational robots have been conducted (Brender et al., 2021; Walker et al., 2016).

Research has been carried out on training teachers in educational robotics, and this has led to the development of course models aimed at enhancing teachers'understanding of programming through active learning methodologies (Fernández Lago et al., 2020). Assessing teachers'pedagogical content knowledge in teaching CT through robot programming has also been a subject of investigation. Studies suggest course models and data collection tools designed to evaluate teachers'competencies in this field (Çakıroğlu & Kiliç, 2020).

A research agenda that seeks to identify the knowledge required for teaching beyond pedagogical content knowledge (Shulman, 1987), including geometric content and technological knowledge (Mishra & Koehler, 2006) is therefore necessary. Within the framework of the Onto-semiotic Approach (OSA) (Godino et al., 2019), the Didactic-Mathematical Knowledge (DMK) considers teachers' technological knowledge (Morales-López et al., 2024).

On the one hand, research aims to explore mathematics teachers'geometric knowledge (e.g., van der Sandt & Nieuwoudt, 2005). There are studies on the teaching of measurement (Browning et al., 2014), visualisation (Merrill et al., 2010), geometric transformations (Pinamang & Cofie, 2017), and geometric shapes and figures (Caviedes et al., 2022; Mutlu et al., 2017); as well as on the classification of polyhedra (Vargas Herrera et al., 2023) and angles and turns (Martín et al., 2021). Research has also been carried out in ECE on teachers' specific knowledge of the teaching of geometry, such as symmetries (Samuel-Sánchez et al., 2018), geometric figures (Lelinge & Svensson, 2020), and prisms (Escudero-Domínguez et al., 2021). No evidence of research addressing the geometric knowledge of future ECE teachers about topological, metric, and projective geometries was found. With respect to teachers'technological and geometric knowledge, the studies by Gómez-Chacón (2013) and Pochulu (2010) stand out.

On the other hand, the literature review on the didactic, mathematical, and computational knowledge of teachers using educational robots includes the use of the Blue-bot robot with future ECE teachers (Sala-Sebastià et al., 2023); the use of mBot, Robot Mouse, and the Makey Makey invention kit with future ECE and primary education teachers (Román-Graván et al., 2019); and the use of the Creative Computational Problem Solving Model (CCPS) in the training of in-service teachers (Chevalier et al., 2021). However, to date, no research has been conducted to map the geometric and computational knowledge of future ECE teachers when working with MatataLab's educational robot, which is essential to improve these future professionals' training.

This study intends to answer the following questions: How to characterise geometric and computational thinking of future ECE teachers when solving geometric problems using MatataLab's educational robot? Which errors do pre-service teachers make when solving the problems proposed?

The objective of this study is to characterise geometric and computational thinking of future ECE teachers based on their participation in a robotic problem-solving activity for 5-year-old pupils, using MatataBot, MatataLab's educational robot, identifying the errors they make.

2 Theoretical framework

2.1 Teachers' mathematical knowledge models

The Onto-semiotic Approach (OSA) (Godino et al., 2019) proposes a model of Didactic-Mathematical Knowledge (DMK) that characterises teachers'knowledge in three dimensions: mathematical, didactic, and meta didactic-mathematical (Pino-Fan & Godino, 2015).

The mathematical dimension of DMK includes common content knowledge, which encompasses the knowledge necessary to solve curriculum problems at a given educational level, and expanded content knowledge, which includes more advanced concepts of the curriculum, or of the next educational level (Pino-Fan & Godino, 2015).

The didactic dimension of DMK is subdivided into specialised knowledge of the mathematical dimension (epistemic facet); knowledge about students' cognitive aspects (cognitive facet); knowledge about students' affective, emotional, and attitudinal aspects (affective facet); knowledge about classroom interactions (interactional facet); knowledge about resources and tools that can enhance student learning (mediational facet); and knowledge about curricular, contextual, social, political, and economic aspects that influence the management of student learning (ecological facet) (Breda et al., 2017; Pino-Fan et al., 2018).

Each component of DMK is analysed using specific theoretical-methodological tools (Godino et al., 2019). This paper focuses on the mathematical dimension of DMK, particularly on the epistemic facet, using the "epistemic configuration" tool, which enables describing and characterising primary mathematical objects: representations (terms, notations, graphs), problem situations, definitions, propositions/properties, procedures (algorithms, computational techniques), and arguments/justifications. They are developed through mathematical processes of communication, problematisation, definition, enunciation, development of procedures, and argumentation in the mathematical practices of the teacher when solving a problem (Torres, 2020), as shown in Fig. 1.

Furthermore, the description and categorisation of errors, such as errors in the definition, in the proposition, in the task instructions, in the representation, in the argumentation, or procedural errors made by pre-service or in-service teachers are addressed from a mathematical perspective (Font et al., 2024).

In essence, the OSA explores the knowledge a mathematics teacher needs, and divides it into three areas: mathematical knowledge, knowledge of teaching strategies, and reflection on teaching. This paper focuses on how future ECE teachers use mathematical concepts (primary objects) when solving geometric problems using MatataBot, MatataLab's educational robot. The most common errors they make are also analysed in this study.

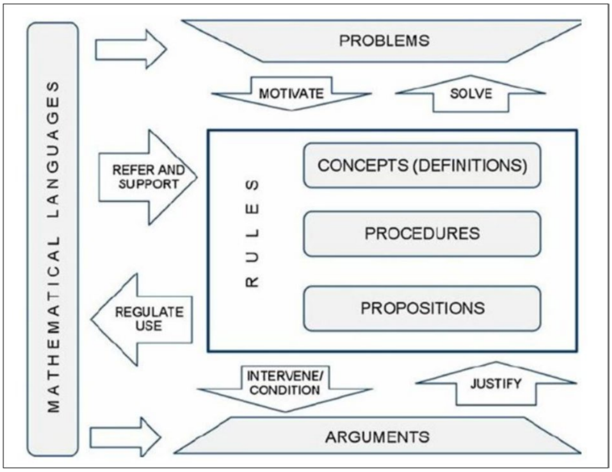


Fig. 1 Configuration of primary objects involved in mathematical practices. Source: (Drijvers et al., 2013, p. 28)

2.2 Early childhood education teachers' mathematical, geometric, and computational knowledge

Alsina and Delgado-Rebolledo (2022) point out that ECE teachers need two types of interrelated knowledge to teach mathematics:

a) Mathematical knowledge of the ECE educational level, which includes intuitive and informal knowledge, mathematical content children need to learn, and mathematical processes.
b) Didactic knowledge of mathematics of the ECE educational level, which refers to knowledge of how children learn mathematics, the planning and management of teaching activities, and curriculum guidelines.

This study focuses on mathematical knowledge, particularly the geometry necessary for ECE. Chamorro (2005) indicates that teachers need to know three types of geometry:

a) Topological geometry: relations that do not change under deformation, such as types of shapes (open, closed), continuity, order, and types of connections
b) Projective geometry: relations that vary with the point of projection, such as up/down, right/left, forward/back
c) Metric geometry: relations that depend on measurement and shapes, including distance, angle, volume, surface, symmetries, and rotation

MatataBot, MatataLab's educational robot, appears as a highly suitable tool for teaching geometry to young children, as they interact with it through a language – referred to as programming language—they should know and assimilate in advance in order to build elementary geometric shapes and forms. The use of this language, which is necessary to give instructions to the robot and enable it to carry out the sequence of movements required to represent a specific shape, shows several properties of that shape.

Likewise, decoding the messages or instructions given to the robot in order to identify which geometric shape it is, enables attention to be focused on its basic properties, and facilitates the understanding of elementary geometry. Moreover, the transition from the use of an egocentric reference system—commonly used by ECE pupils—to the use of an exocentric reference system for spatial representation is encouraged.

The language used to interact with MatataBot uses symbols and intuitive grammar that enables students to represent a shape in space based on their mental representation of the movements to be made by the robot, giving this representation meaning. According to Chamorro (2005), in the last year of ECE (5-year-old children), pupils are able to develop short and easy programmes in order to construct geometric figures. Although this is a complex task, it is considered particularly relevant for children to progressively build an appropriate representation of space based on the basic movements involved.

ECE teachers should therefore master the programming language, as well as the potential and limitations of the robot, to be able to design learning situations including representation activities in accordance with their pupils' level of maturity. In this regard, research in teacher training suggests that future teachers should acquire expanded content knowledge (Pino-Fan & Godino, 2015).

With respect to teachers'computational thinking development, Estebanell et al. (2018) put forward an initial training model that includes four levels: user level, reflective user level, teacher level, and reflective teacher level. This research focuses on the user level. At this level, Seckel et al. (2022) identified common errors in the planning of programming: a) error due to misunderstanding a type of programming, b) error due to the absence of one or more coding blocks, c) error due to excessive quantification of coding blocks, d) error when applying previous knowledge.

Brennan and Resnick (2012), for their part, propose a framework for characterising CT that includes the following three dimensions:

a) Computational concepts: main ideas such as sequences, loops, data, and operators
b) Computational practices: activities for using the robot in a variety of contexts
c) Computational perspectives: changes in the users'view of the computational activity

All elements of the above models help contribute to characterising the knowledge related to CT of the participants in this research.

3 Materials and methods

This research, within the qualitative paradigm (Cohen et al., 2007), is based on a case study (Stake, 1995), the purpose of which is to understand, describe, and explain the characteristics of geometric and computational thinking the participants put to use in the implementation of a learning situation designed by the authors. The teaching objective of this learning situation is to develop geometric and computational knowledge and its didactics, using MatataBot, which is recommended for children aged between 4 and 9 years of age.

3.1 Description of the educational robot used

MatataBot is part of an analogue coding set. As shown in Fig. 2, in which letters of the alphabet are used to name the different parts, the coding set consists of a control board (a), connected to a command tower (b), which reads the commands given

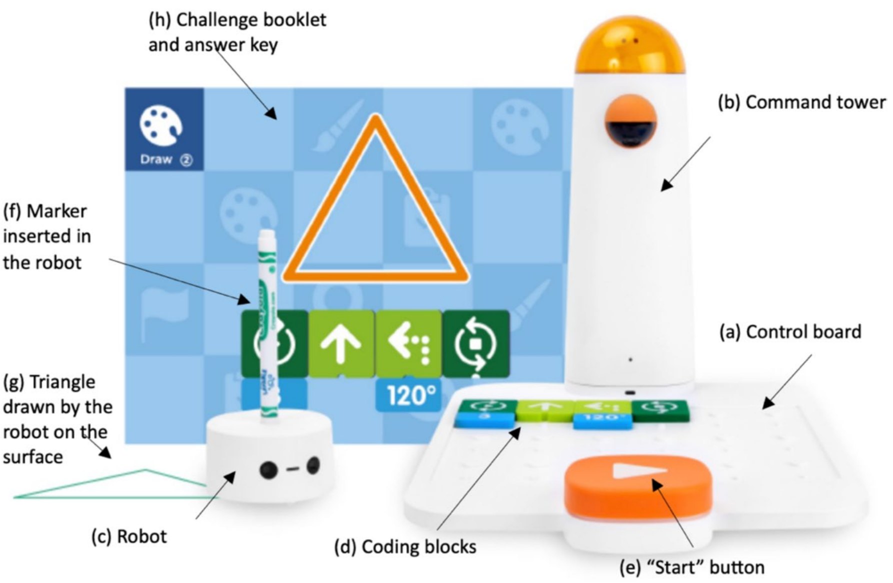


Fig. 2 MatataLab's coding set. Adapted from https://matatalab.com/

and sends them to MatataBot, the robot (c). MatataBot starts moving when the user, after writing the desired programming using coding blocks (d), presses the "start" button (e), symbolised by ►. MatataBot, cylindrical in shape, has a hole in its centre in which a marker (f) can be inserted to mark the route followed on the surface on which it moves (g). The coding set comes with several challenge booklets and activity sheets (h) that include a programming proposal for one of the possible solutions to each challenge or activity.

Fig. 3 Coding blocks in the coding set. Source https://matatalab.com/

The coding blocks have intuitive symbols of the commands they represent (see Fig. 3). There are different types of coding blocks. For instance, there are four types of motion coding blocks (move forward, move backward, turn right, and turn left). The first two can be combined with number coding blocks (2, 3, 4, 5, and random number) for the action of the motion coding blocks to be repeated a desired number of times. The "turn left" and "turn right" coding blocks can be combined with angle coding blocks to specify the degree of the desired turn angle (if not indicated, the turn the robot performs is always 90°). There are also "loop begins" and "loop ends" coding blocks to indicate when the same action has to be repeated. These coding blocks can also be combined with number coding blocks to indicate how many times the loop has to be repeated. Function coding blocks (define function coding blocks and calling function coding blocks) are also available. Other types of coding blocks for the robot to sing different melodies or dance also exist.

The purpose is always to solve a robotic problem (Arlegui & Pina, 2016). In other words, the robot moves from a starting point to another point with a specific purpose (e.g., to draw a triangle starting at one of its vertices, to travel across a map to reach a destination, etc.). To do so, the user has to place the necessary coding blocks on the board (the user can be asked to use as few as possible) to write the programming of the desired route. As soon as the user presses the "start" button, the command tower reads the commands, interprets them, and sends them to the robot for it to complete the movements following the route indicated. Through observation, the user can check if the instructions are correct (i.e., if the robot has completed the expected route). If the route is wrong, the instructions are revised on the control board, the error is identified and rectified, and the robot can start all over again.

Other accessories that come with the coding set are a small square grid map with images on both sides and several plastic pieces like flags or obstacles that can be placed on the routes indicated on the grid map.

3.2 Context and participants

The research participants were 42 third year ECE students taking the subject of Didactics of Mathematics taught by the first two authors of this paper at a Spanish university during academic year 2022–23. They were divided into eight groups (G1 to G8). They were expected to have previous knowledge of geometry, which their teachers had taught them in sessions preceding the study. In those sessions, they learnt about the Van Hiele levels of geometric thinking and about the properties and characteristics of the different types of geometry: topological, metric, and projective geometry. However, most of the students were not familiar with the use of educational robots and programming.

3.3 Description of the task proposed

The task proposed, intended for future ECE teachers, consisted of three phases including different activities that were implemented in a two-hour session that was part of the subject of Didactics of Mathematics. A MatataLab coding set was given to each group.

In phase 1, the students familiarised themselves with the functioning of the robot and the function of each of the coding blocks carrying out an activity. The different groups were asked to solve the first three challenges of one of the challenge booklets using the grid map. These challenges do not present any major difficulty, but the students had to use the motion and number coding blocks. In the last challenge, they had to use the loop coding blocks to “save” coding blocks when programming, as there were not enough blocks to code all the repetitions required without executing loops.

In phase 2, the activities proposed consisted of programming the robot in such a manner that its movements represented various basic geometric figures: a square, a rectangle, an equilateral triangle, and a rhombus, using the marker inserted in its centre. For each of the programming attempts (even if unsuccessful) and their verification, the students had to record a video using their mobile phone and upload it to a platform to later share the link in the reports they had to present in phase 3.

Phase 3 had to be completed autonomously outside the classroom. The groups were asked to submit a report on the task they were given as assessment evidence of the subject. The task in this phase was to identify the different geometric aspects worked on by answering the questions in Table 1 in writing, as well as to include links to the videos of the activities done in phase 2. As part of this task, the students were asked to adopt the role of ECE teachers, and based on the lesson “experienced”, they had to assess it and propose adaptations. They had to consider planning the lesson to teach it in a classroom with 5-year-olds. The results of the analysis of this last phase are not included here, as they respond to an objective that will be addressed in another paper.

The content of the learning situation was meant for pupils in the last year of ECE (5-year-old children), but it was presented in such a manner that it was a challenge for future ECE teachers. In order to implement it with 5-year-old children, all the necessary didactic adaptations would hence have to be made for the lesson to be suitable for the educational context in question.

Table 1 Questions regarding the geometric content of the activities carried out in phase 2

1. Explain which geometries can be developed in the activities carried out using MatataBot. Give a specific example of each of the geometries you mention to justify your answer
2. In the first activity carried out using the grid map and the challenge booklet, what topological, metric, and projective characteristics did you identify? Justify all the characteristics you mention
3. When building the square, what topological, metric, and projective characteristics did you identify? Justify all the characteristics you mention

Authors’ own work

3.4 Data and analysis tools

Data were obtained from the authors'observations during the implementation of the learning situation in phases 1 and 2 (which they triangulated at the end of the session), and from the videos the researchers recorded during the session. Data were also gathered from the reports the eight groups presented in phase 3, which included the responses to the questions in Table 1, and from the videos the students recorded of the development of the activities.

Once the data were collected by the first and second author, a thematic analysis was performed following the six phases of the methodology proposed by Braun and Clarke (2006, p. 87): 1) become familiar with the data; 2) generate initial codes; 3) search for themes; 4) review themes; 5) define themes; and 6) write up the report. It should be noted that Braun and Clarke's (2006) thematic analysis was adapted to the needs of this study. The themes were therefore determined a priori, based on the theoretical framework. To characterise the geometric and computational knowledge of the participants, a qualitative analysis of their answers to the questions in phase 2 and to question 3 in phase 3 was performed. It was based on the notion of epistemic configuration of the DMK model of the OSA (Godino et al., 2019). In this analysis, it was observed that primary objects emerged, and some errors related to these primary objects were detected (Font et al., 2024). For the primary object of procedure, the programming errors the participants made when constructing the geometric figures requested in phase 2 were characterised. To do so, the classification of Seckel et al. (2022) on the frequent errors teachers make when working with educational robots was taken as a starting point. This classification is explained in the theoretical framework section of this paper. The classification of errors made by pre-service teachers in the procedure of programming geometric shapes includes the following: a) *error due to misunderstanding a type of programming*, as they made an error in the number of times the loop coding block had to be repeated; b) *error due to the absence of one or more coding blocks in the programme*, as they did not add the "loop ends" coding block at the end of some programmes, which prevented MatataBot from functioning; c) *error due to excessive quantification of a coding block*, considering they placed an unnecessary quantity of number coding blocks under the "move forward" or "move backward" block; and d) *error when applying previous knowledge*, when they made a mistake in the degree of the turn angle.

The results of the analyses conducted by the authors were triangulated together with two external researchers, experts in the use of the tools described, until a consensus was reached.

Table 2 Primary objects and emerging errors

Categories (Primary objects)	Characterisation	Groups
Phase 2: Programming the robot (using the marker inserted in its centre) to represent geometric figures: a square, a rectangle, an equilateral triangle, and a rhombus		
Representation	Verbal-written	G1, G3, G5
	Symbolic (programming codes using coding blocks)	G1, G2, G3, G4, G5, G6, G7, G8
	Iconic (before programming the robot)	G1, G2, G3
	Iconic (after programming the robot)	G1, G2, G3, G4, G5, G6, G7, G8
Argument/Justification	To construct the rectangle, the loop has to be repeated twice, because the figure has two sides and two sides (two long sides and two short sides)	G1
	It is necessary to move forward and turn four times because it is a square	G3
	When programming the triangle, we chose the double of the 60-degree angle because the robot turns along the external angle, so it is the measure of the external angle	G3
Proposition/Property	The sum of the internal angles of a rhombus is 180 degrees	G3
	In a rhombus, consecutive angles measure twice as much as each other. If one angle is 60 degrees, then its consecutive angle is 120 degrees	G1
	The opposite angles of a rhombus are congruent	G2, G3
	In a triangle, the external angle is twice the measure of the internal angle	G3
	A rhombus is not the same as a square. Its sides are more stretched out	G3
Procedure	Add the consecutive internal angles of a rhombus to verify that one angle is twice the other	G1
	Construct the geometric figures using the coding blocks	G1, G2, G3, G4, G5, G6, G7, G8
	Represent the geometric figures using the marker and paper	G1, G2, G3
Phase 3: Question 3. When building the square, what topological, metric, and projective characteristics did you identify? Justify all the characteristics you mention		
Argument/Justification	Arguments related to topological geometry	G1, G3, G4, G5, G6, G7, G8
	Arguments related to projective geometry	G1, G2, G3, G4, G5, G6, G7, G8
	Arguments related to metric geometry	G2, G3, G5, G6, G8

Authors' own work

4 Results

This section presents the primary objects that emerged throughout the activities, as well the errors the future ECE teachers made with regard to these objects (see Table 2).

4.1 Representations

In the problem-solving activities related to the construction of geometric figures using MatataBot (phase 2), amongst the objects that emerged, there were representations. Three groups used verbal representations of the figures, G1 and G5 of the rectangle and G3 of the square. All the groups used symbolic representations (programming codes of the robot) to represent the four geometric figures (a square, a rectangle, an equilateral triangle, and a rhombus) they were asked to construct. All eight groups employed iconic representations of each geometric figure (drawn from the programming code of the robot). Three groups used iconic representations of the figures before programming the robot. Group G1 represented the rectangle, while G2 and G3 represented the rhombus, indicating the respective angles. However, a lack of geometric accuracy was observed in the representation of the rhombus (error in the representation), as shown in Fig. 4.

Fig. 4 Group G3's iconic representation of the rhombus. Authors' own work

Fig. 5 Programming of a rhombus in which the sum of the internal angles is 330 degrees (less than 360 degrees). Authors' own work

4.2 Propositions/properties

Propositions and properties of geometric figures were another primary object that emerged in the participants'responses. Of the ones that emerged, only one, expressed by groups G2 and G3, was correct. They commented that the opposite angles of a rhombus are congruent. The others could be characterised as errors in the proposition and/or property, since the sum of the internal angles of a rhombus is 360 degrees and not 180, and the consecutive angles of a rhombus do not always measure twice as much as each other (one angle can be 105 degrees and the other 75). In addition, the external angle of a rhombus is not always twice the internal angle.

Regarding the programming for the construction of the rhombus, two groups included angles the sums of which, both of the internal and of the external angles, were greater or less than 360 degrees. As the figure resembled a rhombus, the groups considered the answer (programming) as correct (see Fig. 5). In this case, the future teachers did not take into account the property of quadrilaterals stating that the sum of the internal and external angles of a quadrilateral is always 360 degrees. They hence made an error in the proposition/property.

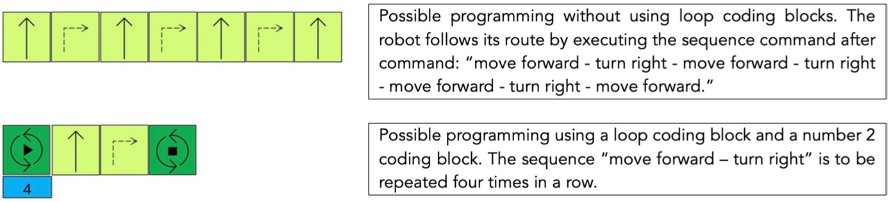
4.3 Arguments

The participants used arguments and justifications in the activities they carried out. On the one hand, in the construction of the geometric figures (phase 2), few groups gave grounds for their solutions. G1 argued that, in order to construct a rectangle, the loop had to be repeated twice because the figure has two sides and two sides (two long sides and two short sides). The members of G3 justified that the robot had to move and turn four times because they wanted to create a square. That same group argued that, when programming the triangle, they chose the double of the 60-degree angle because the robot turns along the external angle, and they therefore had to use the measure of the external angle (120 degrees). The remaining groups did not justify or give reasons for the solutions they presented to construct the figures.

On the other hand, in question 3 (phase 3), arguments emerged to justify the types of geometry that could be identified when constructing the square. The groups used arguments to justify topological, projective, and metric geometry. Regarding topological geometry, the only group that did not present any arguments was G2. Of the groups that did put forward arguments, only three groups offered a complete argument and used all the topological invariants. Three groups presented incomplete arguments, and one group (G1) presented an erroneous argument, as they used the notion of command incorrectly.

> When using a square, you can work on the command, since, to make the robot move, first of all, you have to think and build the sequence of movements that it will make and, therefore, you have to take into account the command of the different blocks because, if you change it, it [MatataBot] will not execute the command correctly. (G1)

With respect to projective geometry, all the groups presented arguments, although most of them did not include all the invariants of projective geometry. As for metric geometry, only three groups offered a complete argument to justify that aspects of metric geometry emerge in the construction of the square. Five groups presented incomplete and inconsistent arguments. For instance, in the argument shown below, some aspects, such as the recognition of plane figures, are not considered. In the construction of the square, the notions of distance and symmetry are not addressed, which could be considered as an error in the argumentation. Group 5 said: "(…) 90-degree angles when constructing the square. Turns: when the robot turns on itself and then moves to the left or to the right. (G5)".



Possible programming without using loop coding blocks. The robot follows its route by executing the sequence command after command: "move forward - turn right - move forward - turn right - move forward - turn right - move forward."

Possible programming using a loop coding block and a number 2 coding block. The sequence "move forward – turn right" is to be repeated four times in a row.

Fig. 6 Correct programming to represent a square using MatataBot. Authors' own work

4.4 Procedures

With regard to procedures, it was observed that group G1 added the consecutive internal angles of the rhombus to verify that one is double the other. Three groups represented the geometric figures using a marker and paper before carrying out the activity with the robot.

In the analysis of the emergence of primary objects, it was also observed that all the groups represented the geometric figures using the coding blocks. However, during the process of representing some of the figures, procedural errors in the programming were made, which caused errors in their iconic representation, as detailed below.

4.4.1 Programming procedure for the square

In the case of the square, the first figure the robot had to represent, the images on the left in Fig. 6 show two examples of possible programming considered as correct. It was likely for the groups to use this type of programming.

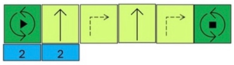
Other programming possibilities exist in which the square can be represented in the same way. For example, if instead of moving forward, the robot moved backward, or if, instead of turning to the right, it turned to the left. All the groups managed to programme this representation without errors.

4.4.2 Programming procedure for the rectangle

For the representation of the rectangle, it was likely for the groups to use programming like the ones in Fig. 7, which shows two examples of possible programming considered as correct.

From the programming of the square onwards, all the groups chose to make use of the loop coding blocks for their next programming. For the most part, the participants made two main mistakes, which are described below. They are based on the example of group G3's programming to represent a rectangle (see Fig. 8).

Possible programming without using loop coding blocks. The robot follows its route by executing the sequence command after command: "move forward - move forward - turn right - move forward - turn right - move forward - move forward - turn right - move forward."



Possible programming using a loop coding block and a number 2 coding block. The sequence "move forward – move forward – turn right – move forward – turn right" is to be repeated twice in a row.

Fig. 7 Correct programming to represent a rectangle using MatataBot. Authors' own work

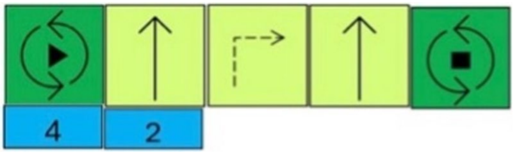


Fig. 8 Erroneous programming to represent a rectangle. Authors' own work

As can be observed, the following two errors in the programming are identified: 1) *Error due to the misunderstanding of a type of programming* (the loop coding block should be repeated twice, not four times); 2) *Error due to the absence of a coding block* (a right-turn coding block is missing before closing the loop). However, a student of Group 3 looked at the instructions and realised the number 4 coding block at the beginning of the loop was incorrect: "It has two sides and two sides. This [pointing to the number 4 coding block] is a 2! There are already two sides here [pointing to the two "move forward" coding blocks]".

To visualise it, they checked it using the graphic representation of the route they followed at the beginning of the activity. They changed the number 4 coding block for a number 2 coding block, but the representation was not correct. A student of Group 3 said: "There have to be four turns [pointing to the number 2 coding block below the "loop begins" coding block]". Another student of that same group replied: "This is not the turn [pointing to the "loop begins" coding block]. It is this one [pointing to the "turn right" coding block]". This same student then realised another turn was missing before the "loop ends" coding block: "Let's put another turn here (G3)".

However, her classmates were not sure about it, and they said: "No, no, lets' try! [and they pressed the "start" button] (G3)".

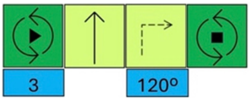
The representation was not correct. A member of G3 said: "Let's add another turn, as M. said (G3)".

Finally, the representation was correct.

4.4.3 Programming procedure for the equilateral triangle

For the representation of the equilateral triangle, it was likely for the groups to use the type of programming in Fig. 9, which shows an example of possible programming considered as correct.

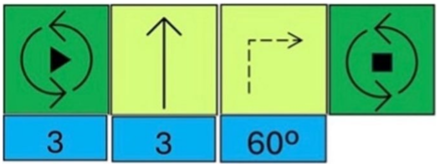
The angle coding blocks of the programming for the equilateral triangle were a source of common errors in all the groups. Group G2's first programming attempt is shown in Fig. 10.



Possible programming using a loop coding block, a number 3 coding block, and a 120-degree angle block. The sequence: "move forward - turn right 120 degrees" is to be repeated three times in a row.

Fig. 9 Possible correct programming to represent an equilateral triangle using MatataBot. Authors' own work

Fig. 10 Erroneous programming to represent a triangle. Authors' own work



As can be seen, the following two errors in the programming were identified: 1) *error due to excessive quantification of a coding block* (the number 3 coding block below the “move forward” coding block is not necessary); 2) *error when applying previous knowledge* (the degrees of rotation should be 120);

When the students checked their programming by pressing the start button of the MatataLab coding set and saw that the figure they expected was not represented, they immediately realised that the number 3 coding block under the “move forward” coding block was not correct, as the robot already moved forward three times using the loop to represent the three sides of the triangle. They also noticed, looking perplexed, that the angle of the triangle was too open. It may be inferred that this is because they know the interior angle of an equilateral triangle has to be 60 degrees, given that all angles must be equal, and because the angle sum property of a triangle says that the sum of its interior angles is equal to 180 degrees. A dialogue among the participants of Group 2 began:

> Your angle is too open. Why?
> I think it (the robot) is turning along the exterior angle. Thus, 360–60 = 300 degrees…
> But there is no angle coding block for 300…
> Let’s use two of 150
> We can’t use two.
> Let’s use one of 150 and let’s try (dialogue in G2)

They then changed the 60-degree angle block for a 150-degree angle block, but the representation did not correspond to an equilateral triangle either.

The explanation is that MatataBot’s angle of rotation is made in relation to the straight line of its route. In other words, to find the angle, it is necessary to calculate the angle complementary to the interior angle of the figure to be represented (see Fig. 11).

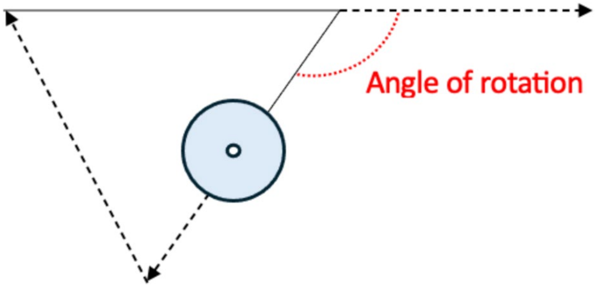


Fig. 11 Angle of rotation of MatataBot. Authors’ own work

After the first attempt, the students, for the most part, did not apply their previous knowledge to reason out what the angle should be in the programming, but found it by trial and error, using the different angle coding blocks that came with the coding set.

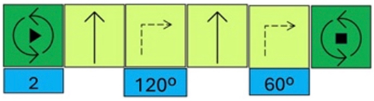
When group G4 realised the 60-degree angle was too wide, they changed it to 45 degrees. As they wanted the angle of rotation of the robot to be more narrow, they reasoned that they had to use an angle that was smaller than 60 degrees. They only looked at the measure of the angle, but without relying on their previous knowledge of triangles. An equilateral triangle could not possibly have interior angles of 45 degrees, as the sum of its angles would not add up to 180 degrees, and the essential property of being a triangle would not be fulfilled. This is another expression of the same type of error when applying previous knowledge.

4.4.4 Programming procedure for the rhombus

For the representation of the rhombus, programming of the type shown in Fig. 12 was considered to be correct.

Most of the errors in the representation of this figure were errors when applying previous knowledge, as they were related to the angles of rotation. This was also the case with the equilateral triangle, despite the fact that the students already had experience in representing it, and had knowledge about the characteristics of rhombuses.

They learnt by trial and error using the angle coding blocks that were available, without thinking about how to find the angles they would have to use for the representation to be correct.



Possible programming using a loop coding block, a number 2 coding block, and the 60 and 120-degree angle blocks. The sequence "move forward - turn right 120 degrees- move forward - turn right 60 degrees" is to be repeated twice in a row.

Fig. 12 Correct programming to represent a rhombus using MatataBot. Authors' own work

5 Discussion and conclusions

This is a qualitative study does not intend to generalise results, but aims to provide knowledge to characterise the geometric and computational thinking of future ECE teachers based on their participation in a robotic problem-solving activity using MatataBot, MatataLab's educational robot. It also seeks to identify which errors they make and the difficulties they face in this process.

From the responses to the activities the future ECE teachers were given, the following primary objects were identified: arguments/justifications, representations/language, propositions and procedures related to mathematical objects. However, it was not possible to identify definitions or concepts associated with a specific mathematical object.

As for the representations, although all the groups used symbolic and iconic representation using the coding blocks, few groups used verbal and iconic representation before executing the programming of the robot, and several errors of accuracy were found in the representation of the geometric figures.

Regarding the propositions or properties of the geometric figures, only one of those that emerged was considered correct from a mathematical perspective. This led to the inference that the future ECE teachers have limited knowledge of the properties of the geometric figures they worked on.

With respect to the arguments the participants presented when carrying out the activities in phase 2, only two groups justified the reason for the construction of the figures. For question 3 in phase 3, all the groups gave grounds for the types of geometries (topological, projective, and metric) that could be inferred in the construction of the square. However, few groups formulated complete arguments that included all geometric invariants, and errors were detected in these arguments.

As for the primary object of procedures, several errors were found in programming the robot. These included errors due to the misunderstanding of a type of programming, to the absence of a coding block, to excessively quantifying a coding block, and to errors when applying previous knowledge.

Although several studies show positive levels of interest, knowledge, problem solving and self-efficacy in future teachers when working on robotics and computational thinking in basic education (Piedade, 2021), this study reveals weaknesses in both mathematical (geometric) and computational (sequence programming) knowledge when solving robotic problems at the user level. This is in line with the studies of Caviedes et al. (2022) on the knowledge of the mathematical object area, and with those of Sala-Sebastià et al. (2023) on the mathematical and computational didactic knowledge of future ECE teachers when using the Blue-Bot robot. It also coincides with the observations of Seckel et al. (2022), who identify different types of errors made by future ECE teachers when solving robotic problems, mainly in the programming procedures of code sequences. These procedural errors can contribute to refining the error classification proposed by Font et al. (2024).

In the case of mathematical practices for programming educational robots to follow routes and make representations, procedural errors often involve errors in the representation. Moreover, in the study conducted, the type of procedural error called "error when applying previous knowledge" could be compatible with "error in the definition" or "error in the proposition" described by Font et al. (2024).

It is hence clear that the participants' lack of previous knowledge of geometry (such as the properties of elementary geometric figures, amongst other aspects) leads to errors in both programming and representation. However, it can be confirmed that future teachers'experiences as learners serve as evidence that geometric knowledge programming activities aligned with state-level mathematics standards and the national curriculum offer promising opportunities for future teachers to improve their CT skills while learning mathematics. This finding is consistent with the study conducted by Dahshan and Galanti (2024). They maintain that the open-ended nature of this kind of activity promotes teachers' ability to make sense of mathematical concepts through code, and to diagnose errors when the programme does not create the mathematical representations they expected. Ye et al. (2023) concluded in their study that integrating CT in mathematics education has proven to be supportive in the content of algebra and geometry across education levels. In this regard, it can be concluded that, although the use of educational robots enhances the understanding of geometry, it is crucial to assess and work on future teachers' previous knowledge before they are faced with levels higher than the user level, such as reflective user level, teacher level, or reflective teacher level, as defined by Estebanell et al. (2018).

The need to train future teachers not only in mathematical-geometric knowledge, but also in the use of technological tools in the classroom (Morales-López et al., 2024) is crucial, as it would contribute to their comprehensive training and to improving ECE teaching. We are in agreement with Yang's (2025) conclusions that participating in innovative teaching practices, in which future ECE teachers are required to experiment with technological tools such as educational robots, could be a stimulus to enable them to confidently design and implement their own activities by experimenting with current technologies in their future teaching practice. Modelling is an effective way of learning how to teach (Ertmer & Ottenbreit-Leftwich, 2010). The findings of this study are also aligned with Dahshan and Galanti's (2024) results when they state that the sequence of experiencing programming as learners followed by reflection on how the programme might fit into their mathematics curriculum equips them with the expertise needed to design similar open and creative learning experiences for their students.

The research here conducted is one of the first approaches to using educational robots for future ECE teachers' development of CT linked to geometric thinking. Based on the results of characterising and identifying errors that could hinder its development, didactic orientations can be implemented to guide specific teacher training. This would complement studies on the existing training, referring to the use of Bee-bot for the development of CT (Seckel et al., 2023). These didactic orientations could be written in collaboration with other international researchers in the field. This line of research has recently opened up, and there are numerous reasons, such as the ones mentioned throughout this paper, to continue expanding it. It is key for pre-service teachers to be trained in these skills and competencies, as both the curricula and the needs of current and future society demand them. It allows them to develop those competencies in their future students. Moreover, the development of CT by integrating different mathematical contents, such as geometry in the activity using MatataBot in this study, could open the door to a new way of learning mathematics, making the abstract more specific.

Acknowledgements This study was carried out thanks to the following projects: Pensament Computacional i robòtica amb perspectiva de gènere a l'educació Infantil i Primària (Computational Thinking and Robotics from a Gender Perspective in ECE and Primary Education), Reference: EDU145/23/000006, funded by the Department of Education of the Government of Catalonia. Acknowledgements also to IREUB (Institut de Recerca de la Universitat de Barcelona); and to the project I+D+i PID2021-122326OB-I00, funding by MCIN/AEI/10.13039/501100011033.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This study was carried out thanks to the project called *Pensament Computacional i robòtica amb perspectiva de gènere a l'educació Infantil i Primària* (Computational Thinking and Robotics from a Gender Perspective in ECE and Primary Education). Reference: EDU145/23/000006. It was funded by the Department of Education of the Government of Catalonia.

Data availability The data presented in this study (students' productions, author's notes, and photographs taken) are not public documents, but they can be requested from the corresponding author who would send them after having anonymising them due to privacy restrictions.

Declarations

Employment Not applicable.

Financial interests and non-financial interests There is no undisclosed financial or non-financial interest that would embarrass the author if it became publicly known after the work's publication.

Institutional review board statement This study has followed the Code of Ethics on Integrity and Best Practices by the University of Barcelona (available at http://hdl.handle.net/2445/137937 accessed on 10 January 2024.) and it was approved by the committee of the PhD Programme Didactics of Sciences, Languages, Arts, and Humanities of the University of Barcelona, on 18 July 2023.

Competing interests The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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