MindMaths: learning mathematics in the early years through computational thinking and robotics

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Resumen: Las matemáticas en la educación en la escuela primaria siguen siendo un gran desafío. Los conceptos y habilidades matemáticas a menudo se identifican, tanto por estudiantes como por maestros, como aquellos con las mayores dificultades de aprendizaje. Explorar la robótica educativa puede asumir una estrategia facilitadora y de poder para promover el aprendizaje del conocimiento matemático (conceptos, procedimientos y métodos). El desarrollo del pensamiento formal, el razonamiento matemático, el pensamiento computacional y las habilidades de resolución de problemas pueden estar mediados por escenarios de aprendizaje tangible, ensamblar contextos significativos donde los alumnos pueden manejar y programar robots para aprender matemáticas. Por lo tanto, es importante trabajar en estos enfoques con futuros maestros de su capacitación inicial. Esta es la idea central detrás del desarrollo del proyecto transnacional MindMaths: desarrollar un conjunto de recursos, un curso curricular y recursos educativos, en el contexto de la capacitación inicial de los maestros, para liberar la ansiedad matemática con el uso de robots en el aprendizaje de las matemáticas.
Palabras clave: Educación Matemática, Robótica, Pensamiento Computacional.

Abstract: Mathematics in primary school education remains a great challenge. Mathematical concepts and skills are often identified, both by students and teachers, as those with the greatest learning difficulties. Exploring educational robotics can assume a facilitating and empowering strategy to promote the learning of mathematical knowledge (concepts, procedures and methods). The development of formal thinking, mathematical reasoning, computational thinking and problem-solving skills can be mediated by tangible learning scenarios, assembling meaningful contexts where pupils can handle and program robots to learn mathematics. Therefore, it is important to work on these approaches with future teachers from their initial training. This is the central idea behind the development of the MindMaths transnational project: To develop a set of resources, a curricular course and educational resources, in the context of initial teacher training, to release math anxiety with the use of robots in math learning.
Key words: Mathematics Education, Robotics, Computational Thinking.

1. Introduction

MindMaths is an EU-funded project, started in 2020, with partners from Portugal, Italy, Turkey and Latvia, aiming to cope with math anxiety and problems with mathematics learning in primary education, using educational robotics. Throughout Flipped Learning Practices its focus is on initial primary teacher training, designing learning activities and resources to fulfill this challenge of preparing the future teachers to use robotics to release math anxiety. In the case of school mathematics, anxiety as an emotion that is characterized by a set of reactions to a certain thing or context is common and can have several causes, highlighting, the difficulties experienced in their learning and also the social conceptions about the discipline, which associate it with some difficult and not pleasant. Currently in Portugal, the development of Computational Thinking (CT) is one of the transversal skills in the curriculum documents of the first years, which frames the pertinence of the relationship between two areas and makes the reflection on the potential of Robotics and the CT even more emergent for learn mathematics in the early years.

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This paper presents an overview of the MindMaths Project and the main ideas underlying its development in the Portuguese context. It frames the more relevant learning issues in primary math education, presents the most significant initiative of programing and robotics in the Portuguese scene and discuss the potential that Computational Thinking and robotics offer for learning meaningful mathematics in the early years. It also presents a pilot study in a polytechnic school with the participation of 20 students, future teachers, discussing the main ideas of its development and results.

1.1. Defining a framework

1.1.1. Computational Thinking and robotics in Portugal primary school contexts.

The importance of coding and robotics across the K-12 curriculum has been strongly recognized in the basic education context. Robotics can improve motivation and children engagement, boost collaboration and foster Computational Thinking. Computational Thinking is a powerful and gathering idea to enable students to develop skills considered essential for the full education of citizens of the XXI century. However, contours, understandings and appropriation of this concept are not consensual, making it important and crucial to find a rationale to foster these significant learnings and skills in basic education. The seminal work of Wing (2017) introduces the idea of thinking like a computer scientist, focusing on a way of thinking rather than on digital skills and abilities, “Computational Thinking is the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer—human or machine—can effectively carry out” (Wing, 2017). This way of thinking encompasses skills such as abstraction, algorithmic thinking, automation, decomposition, debugging, and generalization and can be learned in “unplugged” scenarios, without technology, focusing on problem formulation, problem representation and communication and problem solving (Bocconi, 2016). Kafi (2016) extends the idea of Computational Thinking to computational participation, as coding is no longer a solitary, tool-based activity and Computational Thinking and programming are social creative practices. Children valued in their learning process the creation of something real and tangible that can be shared with others. Participation highlights the importance of the communities of practice that has become a key for learning to code. Scratch community is a paradigm of this participation and collaboration, where children share and remix their ideas and projects (Resnick, 2019).

Historically children have played with physical objects to learn a variety of skills. Tangible interfaces may be of significant benefit to education by enabling children to play with actual physical objects augmented with computing power (O’Malley, n.d.). Educational robotics gives children the opportunity to relate tangible concepts with programming and Computational Thinking. In this way, educational robotics is driven in Papert’s constructionism approach Papert, 1980), engaging children in making their own meaningful constructions, “objects-to-think-with”, to accomplish better achievements and significant learning (Papert, 1993).

Align with other international politics and initiatives, Portuguese educational policies recognize the importance of developing Computational Thinking from an early age. As said before, curriculum guidelines for the 1st cycle of the Portuguese primary education system assumes Information and Communication Technology (ICT) as a cross-cutting area, challenging a significant based-curriculum approach to integrate ICT, fostering meaningful learning in the several curriculum areas. This movement goes beyond the narrow idea of preparing more well-equipped programmers and engineers, as it is a broader approach to empower children problem solving, creativity, communication or abstract thinking skills.

In 2015 the ministry of education launched an initiative entitled “Introduction to Programming in the 1st cycle of basic education”, aiming to develop Computational Thinking, digital literacy and transversal skills (IniProg, 2020). Children should develop decomposing and solving problems skills, apply algorithmic thinking, create animated stories and build games using computer programs. In a methodological perspective the activities should draw upon different curriculum areas and students should work in groups to build their projects. Creativity and diversity should be encouraged, as well as sharing projects with others. (Ramos, 2016).

The initiative “Probótica”, programing and robotics in basic education (ME, 2022), followed this first two year project, which ended up involving more than seventy thousand students. In a similar way it favours skills and competences across the curriculum based on learning scenarios that can make learning more active and meaningful. Robotics provides a deeper learning of technology, fostering students to "learn by doing", in a tactile way. Gathering technology, programming languages and tangible objects students can explore problems and visualize results. Thus the initiative aims to contribute to the development of skills associated with computing, increase students' digital literacy levels and promote transversal skills to the curriculum. In short, portuguese governmental initiatives to introduce programming and robotics in primary schools are grounded and sustained in the development of Computational Thinking in a multidisciplinary and based curricula approach.

1.1.2. Robotics and Mathematical Education.

There are several common processes between the development of Computational Thinking and the learning of mathematics, mainly at the level of problem solving, reasoning (thinking at multiple levels of abstraction) and the representation of ideas.
More systematically, elements such as (abstractions and pattern generalizations; information processing; symbol systems and representations; algorithmic notions of flow of control; structured problem decomposition; iterative, recursive, and parallel thinking; conditional logic; efficiency and performance constraints; debugging and systematic error detection) are widely accepted as comprising CT and form the basis of curricula that aim to support its learning as well as assess its development (Grover, 2013).
Mathematics is an area that, in a very natural way, can create numerous and significant opportunities for the development of algorithmic thinking at any level of education and, in particular, at the early years level. In an almost equivalent way, by the very nature of Mathematics, algorithmic thinking is a fundamental process for those who study, apply or do Mathematics. Several researchers claims that children engaging with programming robots have opportunity to explore spatial concepts, problem solving, measurement, geometry, and engage with meta- cognitive processes (Clements, 1993), (Yelland, 1994).
In 1993, R. Hembree and H. Marsh (1993) published several studies that highlight the role of problem solving in the development of mathematical thinking in younger children. In general, problem solving involves steps such as i) understanding the problem; ii) devising a plan to solve it; iii) executing that plan; iv) reflecting on the work. There are several classifications for problem typologies. The best known include one-step problems, two- or more-step problems, process problems, application problems and puzzle-type problems (Bers, 2018). Process problems, which use mechanised or standardised processes, and application problems, which include the collection of real-life data, involving one or more solving strategies will be those that resort to thinking mechanisms closest to those used in the creation, use and representation of algorithms.
In problem solving strategies, we find ideas very close to the ideas of algorithm creation such as pattern discovery, logical deduction or reduction to a simpler problem. For example, games as mathematical tasks require ways of solving problems, with the use and analysis of different strategies, defined objectives and often involve the use of algorithms with structures of various natures such as structures of selection or repetition during their resolution. Also the work with algorithms of arithmetic operations or the discovery of patterns (geometric, numerical, ...) approaches the logic of the use/reuse and evaluation of algorithms of various natures.
In fact, Computational Thinking represents a form of analytical thinking very close to the mathematical thinking form, particularly at the level of problem solving. Thus, programming, Computational Thinking and algorithmic thinking provides a significant opportunity to engage in logical, abstract and sequential thinking, problem solving and the creative design process (Quigley, 2019).
Tasks that involve Computational Thinking and robotics offer significant learning opportunities because they retrieve many of the actions that children perform and see performed in their daily lives, while facilitating the integration of more abstract mathematical thinking into their world and providing the mobilisation and representation of logical reasoning, simpler or more complex, fundamental to solving challenging problem situations, using various strategies, properties or mathematical relationships allowing the development of solid and creative thinking. In this sense, working on the basis of

programming and robotics problems enables the deepening of fundamental knowledge and skills for learning meaningful mathematics through multidisciplinary and authentic learning contexts at the early years level.

As mentioned, in Portugal, new mathematic programs are already in practice and Computational Thinking is consider a transversal skill to develop since the first school years (ME, 2022). In this way, coding and Computational Thinking are being explicitly integrated into the curricular guidelines for the teaching and learning of Mathematics.

2. The MindMaths Project

MindMaths is a two year Erasmus+ project coordinated by Koacaeli University – Turkey and with Polytechnic Institute of Viseu – Portugal, Scuola di Robotica – Italy, Latvijas University–Latvia, Canakkale Onsekiz mart University – Turkey and Educloud Egitim Organizasyon Teknoloji Ticaret Ld – Turkey, as partners (MindMaths, 2022). It intends to develop, in the context of the initial primary teacher training, learning scenarios that explore new approaches to mathematics teaching, tackling the resistance and anxiety that some children show regarding math contents. MindMaths covers primary education level because it is the most appropriate period for recognition and early intervention of children with Math Anxiety. Thus, the aim of this international project is to develop skills for future teachers, who will teach in the early years, in solving possible problems related to mathematical anxiety on the part of their students. Computational Thinking, coding and robotics framed a collaborative development of a teacher training module about teaching/learning mathematics along with the development of a video library to be implemented in all partner countries.

The main intellectual outputs of this project can be retrieved in the project website ((MindMaths, 2022).

The modular course curriculum was designed in a Flipped Learning approach and integrates 5 modules, in a total of 28 face-to-face. Through this modules the students, future primary school teachers, has the opportunity to learn about Math Anxiety, the use of robotics in Math education, to discuss and reflect about alternative methodological approaches, such as flipped learning and blended learning, and to explore, plan, implement and reflect about the use of robotics in mathematics education in primary schools. The video library share videos introducing each learning activity supporting the flipped learn approach. All these resources were tested in a pilot study in each of the partner countries.

3. MindMaths: the portuguese pilot study

In Portugal, the MindMaths course was attended by 20 students of the 3rd year (6th and last semester) of the Basic Education bachelor course in a polytechnic school of education. The average age of students is 22.4 years and 90% are female. Throughout the Basic Education course, students attended some subjects corresponding to a training component in the teaching area, within the scope of Mathematics: Fundamentals of Mathematics, Geometry I (Euclidean Geometry), Numbers and Operations, Algebra, Mathematical Modeling, Geometry II (Coordinate Geometry), Statistics and Probabilities and Manipulating Materials in the teaching and learning of Mathematics. In addition, a discipline of Information and Communication Technology is included in the syllabus of the course. None of the students participated in any previous training on educational robotics.

The course explored teaching methodological approaches to support active and significant learning. Flipped and blended learning, debates, collaborative work and a focus on hands on activities, supporting the students to experience and reflect about the use of robotics in mathematics primary education. In addition to the face-to-face activities, in the polytechnic school of education, students went in small groups to a primary school to promote extracurricular activities with a group of 10 children. This dynamic was crucial to allow students to plan teaching learning scenarios, implement the activities with children and assess the real potential of robotics to teach mathematics.

To develop the activities they used Doc robots with children 6-8 years old, and Mbot robots with children 9-10 years old.

Some of the learning activities are proposed in the MindMaths curriculum. But the students also add some new proposals to be explored with the children. For instance, they proposed a supermarket scenario, fig. 1, to challenge the robot to go shopping the ingredients to make a chocolate cake.

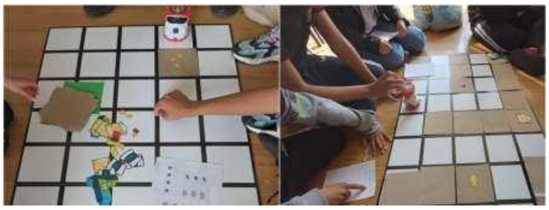

Figure 1. Children playing with the Doc Robot in the supermarket scenario

To accomplish this task, children developed spatial skills, numeracy, measures and estimation.
Other tasks were developed using the Mbot robot, programmed in block language, as shown in the figure 2.

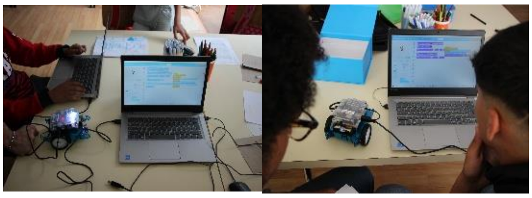

Figure 2. Children playing with the Mbot Robot in different tasks

The 20 students answered to a pre-test and pos-test, both with the goal of understanding their perspectives on the use of educational robotics to learn Mathematics, the knowledge they have in the area and the confidence to use this resource in the subject classes in the 1st cycle of basic education.
A quantitative analysis of the data was performed with determination and interpretation of absolute and relative frequencies, measures of central tendency and dispersion (through the coefficient of variation - CV) to assess the representativeness of the mean. We considered the CV as a measure that evaluates effectively the representativeness of the mean as a central tendency measure, combining the relationship between this measure and the standard deviation. In general, the reference value used for the CV is 50%.
The Wilcoxon test was used to assess the significance of the evolution of the results from the pre to the post-test, in our case with a significance of 5%. In the Wilcoxon statistic we calculate the p-value that is a probability that measures the evidence against the null hypothesis (ie against the hypothesis that t
here were no significant changes from pre to post test). A smaller p- value provides stronger evidence against the null hypothesis). With a significance of 5%, if p-value ≤ 0.05, the difference between the medians is significantly different (and so we reject the null hypothesis).
The tests were divided into 4 sub-dimensions for analysis: Benefits (10 questions), Attitudes (6 questions), Negative perspective (6 questions) and Self-confidence/confidence (8 questions). Each of the test questions had response options within a discrete scale of 1 to 5 where 1 represents strongly disagree, 2 disagree, 3 neither agree nor disagree, 4 agree and 5 strongly agree. Table 1 presents the data related to the means and respective CV calculated for each question of the 4 dimensions, in the pre and post-test.

		Pre-test		**Post-test**	
		Av.	**CV**	**Av.**	**CV**
BENEFITS Sub-Dimension	1. I think that using Robotic Application increases academic success in mathematics lessons.	3,8	15%	4,3	17%
	2. I think that using Robotic Application increases the performance of the teacher in mathematics lessons.	3,8	20%	4,2	18%
	3. I think that using Robotic Application enables students to have fun in math lessons.	4,2	13%	4,6	16%
	4. I think that using Robotic Application enables learning by doing and experiencing in mathematics lessons.	4,3	11%	4,6	16%
	5. I think that using Robotic Application provides a learner-centered teaching approach in mathematics lessons.	3,8	15%	4,2	22%
	6. I think that using Robotic Application is effective in motivating students who have negative attitudes towards mathematics in mathematics lessons.	4,0	16%	4,3	23%
	7. I think using Robotic Application makes math problems more meaningful for students.	4,0	19%	4,2	17%

	8. I think that using Robotic Application in Mathematics lessons will improve students' thinking skills.	4,1	15%	4,2	19%
	9. I think that the topics in Mathematics can be made more concrete by using Robotic Application.	3,6	16%	4,3	19%
	10. I think that using Robotic Application in Mathematics lessons will motivate students to solve complex problems.	3,7	15%	4,2	20%
ATTITUDES Sub-Dimension	1. I am willing to use Robotic Application in Mathematics lessons.	3,8	13%	4,3	19%
	2. I like/I think I will like to use Robotic Application in Mathematics class.	3,8	16%	4,2	20%
	3. I would like to do new research on the use of Robotic Application in Mathematics class	3,7	26%	4,0	22%
	4. I would like/like to develop different Robotic Application designs to use in the Mathematics lesson.	4,1	17%	4,3	19%
	5. I like to learn new information about the use of Robotic Application in Mathematics class	4,2	18%	4,3	19%
	6. The processing of mathematics lessons with Robotic Application applications attracts my attention.	4,1	15%	4,2	19%
NEGATIVE PERSPECTIVE Sub-Dimension	1. I think that methods such as Robotic Application in teaching mathematics are a waste of time.	1,7	52%	1,4	67%
	2. I am not so sure that methods such as Robotic Application can be useful in teaching mathematics.	2,0	47%	1,6	70%
	3. I think that methods such as Robotic Application are overemphasized in mathematics teaching.	1,8	43%	2,1	52%
	4. I think that using Robotic Application in Mathematics lessons removes the clarity about what is learned.	1,8	40%	1,8	63%
	5. I think that using Robotic Application in Mathematics lessons confuses students.	1,9	38%	1,5	63%
	6. I think that using Robotic Application in Mathematics lessons is too costly.	2,8	32%	2,4	43%
SELF-CONFIDENCE/CONFIDENCE Sub-Dimension	1. I think that I am sufficient in creating different scenarios forRobotic Application applications in mathematics teaching.	3,3	22%	3,8	22%
	2. I think/I can use Robotic Application applications effectively in mathematics lessons.	3,4	20%	4,0	21%
	3. I don't think I will have any difficulties while programming robots in robotics applications in math class.	2,9	27%	3,8	20%
	4. I think that using robotic applications in mathematics lessons can force me.	4,1	13%	4,1	24%
	5. Robotic App is easy for me to learn to usein Math Lessons.	2,9	30%	3,8	21%
	6. I think that I have improved myself on Robotic Application in the field of mathematics teaching.	3,8	19%	4,2	20%
	7. I have enough knowledge of Robotic	2,3	40%	3,6	18%
	Application to use in Mathematics Lessons.				
	8. If I try, I can program a robot to usein Mathematics lessons.	2,9	29%	4,0	18%

Table 1. Means and coefficient of variation – pre-test and post-test

In the pre-test, from the data presented, we highlight the fact that 75% of the questions related to the benefits, attitudes and self-confidence/confidence dimensions had averages above (approximately) 4 on the considered scale (which corresponds to the recognition of agree and strongly agree), all representative given that the CV is less than 50%. These facts may reveal that students, even before the development of workshop, recognize the educational potential of robotics to learn mathematics in the 1st Cycle of Basic Education. The post-test r answers accentuate this trend in recognizing the educational potential of robotics, with a more significant increase of 33% corresponding to confidence in programming robots to teach mathematics (question 3 of the self-confidence/confidence dimension) or 20% in what it concerns the recognition that mathematics is more concrete by working with robots (question 9 of the benefits dimension).

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Regarding the Negative perspective dimension, students respond in a more diverse way. In these cases, the means of agreement are the least representative among all dimensions because they are associated with higher CV. In any case, the respondents' opinions improve the idea of the importance of robotics for learning mathematics, considering that its use in mathematics classes is not a waste of time because it is useful and makes abstract concepts clearer. Still on this dimension, students recognize that using Robotic Application in Mathematics lessons is too costly (highest and most representative average agreement in this group of questions).

The questions with the lowest frequency of agreement in pre-test were, in the first dimension, question 9 (47%) and in dimensions two and four, questions three and seven, respectively (37% and 89%). Regarding the third dimension, there are high levels of disagreement with statements, particularly about the first, third, fourth and fifth (100% of responses that represent disagree and strongly disagree). In the post-test, the non-agreement with the ideas associated with the negative perspective dimension (all with more than 89% of frequency) stands out with high frequency. In the pre-test, the answers with the highest levels of agreement are associated with questions three and four of the first dimension, five of the second dimension and four of the fourth dimension (95%, 100%, 89% and 89%, respectively). In the post-test, the highest frequencies of fours and fives (which correspond to agreement or total agreement) were attributed to questions one, three, four and five of the first dimension (95%), one, four, five and six of the second dimension (89%) and six and eight of the last dimension (84%).

The analysis of the data to compare the students' responses from the pre to post test, using the paired Wilcoxon test (with a significance of 5%), confirms the strong tendency for students to recognize: [p-value equal to 0.0270] the importance of using Robotic Application in mathematics lessons because it increases the performance of the teacher (question two of dimension one); [p-value equal to 0.0095] that educational robotics makes mathematics more concrete (question nine of dimension one); [p-value equal to 0.0015] that they are sufficient in creating different scenarios for Robotic Application applications in mathematics teaching (question one of the fourth dimension); [p-value equal to 0.0032] that Robotic App is easy to learn to use in Math Lessons (question five of the fourth dimension).

The following representation, fig. 3, allows comparing the means of answers in each dimension, in two tests.

COMPARISON OF AVERAGES BY DIMENSION

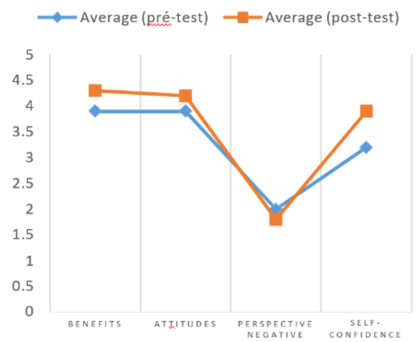

Figure 3. Pre-test and post-test averages by dimension

From the information it's possible to conclude that the averages of agreement with the statements are always higher in the post-test, regarding the benefits, attitudes and self-confidence dimensions. As expected, the opposite is true for the data on the negative perspective dimension.

It is also shows that the levels of agreement with the statements are higher in the questions associated with the first two dimensions for any test: benefits and attitude (for any dimension the averages are representative, since that the CV is always less than 3% in the case of the first, second and fourth dimensions and less than 20% in the perspective negative dimension).

4. Conclusion

Computational Thinking, coding and robotics are strongly recognized as crucial since early education. However, its representations and appropriations are not consensual, as some educational practices persists in teaching coding by coding without exploring the real opportunities of Computational Thinking to scaffold children to formulate, express and represent a problem and propose solutions.

Reactions associated to anxiety in school mathematics can have several causes, highlighting, the difficulties experienced in children learning, and also the social

conceptions about the discipline, which associate it with something not pleasant. Working with technology on real and significant contexts about meaningful problems for children enables them to learn mathematics better and to feel more confident, reducing anxiety in learning the subject. Robots and tangible objects can assume an important role to connect concrete to abstraction thinking, a crucial process in mathematics learning.
MindMaths project explored, in real initial teacher education settings, an approach to foster the use of educational robotics to teach mathematics. Results about the impact on the students, future primary teachers, encourages to address this challenge both in initial training and in in-service training.
In this sense, it is important to rethink how to prepare future teachers to promote authentic and significant teaching/learning mathematics activities, based on Computational Thinking and robotics, promoting better children engagement and learning with math topics. This is the main goal of the MindMaths Project.

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