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Research article

Promoting Effective Math Learning with Educational Robots

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Abstract

Mathematics is a key subject for building competencies of the future. Managing students' attitude towards learning mathematics is an important challenge in the Romanian educational system. Thus, it is essential to bring new teaching practices into the class in order to reduce math anxiety, increase motivation and successfully develop students' cognitive skills. Due to the increasing importance of technology in our lives, using educational robotics may be an effective strategy to meet those demands. The aim of the present study was to design and test 5 educational robots-based scenarios for teaching math competencies, as logical, spatial and computational thinking, in primary school setting. More specifically, we describe the scenarios for robot-supported teaching, the competencies aimed to be developed and the process of testing their effectiveness in class. Main challenges and further recommendations in promoting math learning with educational robots for primary school children are also discussed.

Keywords:
teaching mathematics; primary school; educational robots; technology.

Zusammenfasung

Mathematik ist ein Schlüsselfach für den Kompetenzaufbau der Zukunft. Die Einstellung der Schüler zum Mathematiklernen zu steuern, ist eine wichtige Herausforderung im rumänischen Bildungssystem. Daher ist es wichtig, neue Unterrichtspraktiken in den Unterricht einzuführen, um Mathematikangst abzubauen, die Motivation zu steigern und die kognitiven Fähigkeiten der Schüler erfolgreich zu entwickeln. Aufgrund der zunehmenden Bedeutung von Technologie in unserem Leben kann der Einsatz von Bildungsrobotik eine wirksame Strategie sein, um diesen Anforderungen gerecht zu werden. Ziel der vorliegenden Studie war es, fünf auf Lernrobotern basierende Szenarien für die Vermittlung mathematischer Kompetenzen wie logisches, räumliches und rechnerisches Denken im Grundschulumfeld zu entwerfen und zu testen. Konkreter beschreiben wir die Szenarien für robotergestützten Unterricht, die anzustrebenden Kompetenzen und den Prozess der Prüfung ihrer Wirksamkeit im Unterricht. Außerdem werden die wichtigsten Herausforderungen und weitere Empfehlungen bei der Förderung des Mathematiklernens mit Lernrobotern für Grundschulkinder besprochen.

Schlüsselworte:
Mathematikunterricht; Grundschule; Lernroboter; Technologie.

1. Introduction

In an effort to continuously improve the quality of mathematics teaching, educators and researchers are increasingly turning to innovative technologies as valuable allies in the learning process, especially when working with children. Among these technologies, educational robots have emerged as interesting and potentially transformative tools for improving the mathematics learning experience. Accepting these changes transformed the educational landscape into one that is characterized by evolving teaching methods that incorporate technology and bring it into the classroom. The role of educational robots in promoting effective mathematics learning is becoming a research topic because of the need and responsibility that education will always have, namely to keep the right path and subdue technology to serve accomplishing its aims, and not the other way around.

Equipped with a variety of sensors, interactive interfaces, and customizable programming, educational robots can engage students in new way, more commune to their mindset and needs. Their potential to provide personalized, dynamic, and immersive mathematics learning experiences is promising for educators who want to meet the diverse requests of their students. With this in mind, it is important to conduct a comprehensive investigation into how educational robots can act as catalysts for effective mathematics learning.

This article sets out to explore the role of educational robots in promoting the effectiveness of mathematics learning. The purpose of our study is to expound the benefits, challenges, and pedagogical implications of integrating these robotic companions into mathematics classes via scenarios-based activities designed starting from specific competences set in the curriculum. By delving into the practical experiences of educators and the results observed among students, we aim to provide valuable insights into the potential of educational robots as powerful tools for increasing mathematical literacy, enthusiasm, and achievement in modern classrooms. Through a thorough examination of the scenarios, we aim to show how to realize the full potential of educational robots for effective mathematics teaching.

2. Theoretical foundation

Where does math anxiety start?

Math anxiety is a common phenomenon that affects individuals across various age groups, but it often begins in childhood, grows in early years of school and can persist into adulthood. Math anxiety can have significant negative consequences on a child's academic performance, self-esteem, and future career prospects (Barroso et al., 2021a). Therefore, understanding its origins is crucial for educators and parents to develop effective interventions.

One of the primary contributors to math anxiety in children is early negative experiences with mathematics. Ashcraft and Moore (2009a) suggest in their research that children who encounter difficulties with math early on may develop anxiety as a response to these negative experiences. These experiences could include struggling to grasp basic concepts, receiving poor grades, or facing teacher criticism.

Parents play a crucial role in shaping a child's attitudes and beliefs about math. Studies have demonstrated that parents' own math anxiety and negative attitudes toward math can be transmitted to their children. Children with math-anxious parents may internalize these negative views and develop their own math anxiety (Cosso et al., 2023; DiStefano et al., 2020; Guzmán et al., 2023).

Children are often exposed to peer comparisons and social pressure regarding their academic performance, including math. Children who perceive themselves as falling behind their peers in math abilities may experience increased anxiety. Fear of judgment from peers can exacerbate math anxiety, leading to a vicious cycle of avoidance and further anxiety (Barroso et al., 2021b; Schaeffer et al., 2021; Szczygieł & Pieronkiewicz, 2022).

Another crucial factor in generating math anxiety is evaluation. Math anxiety is closely linked to test anxiety, which can be particularly pronounced during exams and assessments. Children with math anxiety may experience heightened physiological stress responses during math tests, such as increased heart rate and sweating (Álvarez-Bueno et al., 2017; Roos et al., 2023; Whiting et al., 2021). These physical symptoms can reinforce negative associations with math.

Mathematics anxiety and learning mind setup

Research suggests that a significant percentage of students experience anxiety and negative emotions related to mathematics, working memory, arithmetic achievement which can impact their academic performance and overall well-being (Ashcraft, 2002; Ashcraft & Kirk, 2001; Ashcraft & Moore, 2009b; Ashkenazi & Danan, 2017; Balt et al., 2022; Dowker et al., 2016; Harari et al., 2013; Pelegrina et al., 2020; Sorvo et al., 2017, 2019; Zhang et al., 2019).

Research has consistently shown that math anxiety has a detrimental impact on a child's learning outcomes (Barroso et al., 2021a). Children with high levels of math anxiety tend to perform worse in mathematics exams and are less likely to pursue STEM-related fields in the future (Beilock & Maloney, 2015; Daker et al., 2021; Ramirez et al., 2013). This suggests a need for early interventions to mitigate the effects of math anxiety in primary education.

Some studies have highlighted gender differences in math anxiety, with girls often reporting higher levels of math anxiety than boys (Szczygieł, 2020; Wang, 2020). This gender disparity can contribute to the underrepresentation of girls in STEM fields. Understanding the factors that contribute to these gender differences is an important area of research.

Educators and researchers have explored various interventions and strategies to reduce math anxiety in primary school children. These may include teacher training programs, cognitive-behavioral interventions, creating a supportive learning environment and using technology (Chen, 2019; Gabriel et al., 2020; Jenifer et al., 2022; Samuel & Warner, 2021). Research indicates that such interventions can be effective in alleviating math anxiety and improving math performance.

Anxiety is definitely a learning barrier. It increases when related to mathematics because, by the nature of the subject, the student is put in the situation were not only he/she has to be inside the mind in order to generate a solution that need to be exposed, but also the process often needs to be rapid. The more abstract the process is, the harder is for most students, especially for those that benefic a different king of intelligence, not a logical one. So the main question that teachers need to ask is how they can transpose the same mathematical task into an activity that engages students and without them noticing, reduces their anxiety.

Neutralizing math anxiety through learning strategies

Given the importance of the subject and the reverberations of it in all school path, reducing math anxiety in primary school students is crucial. Teachers play a pivotal role in building effective learning strategies and activities to alleviate math anxiety among their young learners. To begin, teachers should establish a nurturing and non-judgmental classroom atmosphere (Álvarez-Bueno et al., 2017; Roos et al., 2023; Szczygieł & Pieronkiewicz, 2022). Encourage open communication and emphasize that making mistakes is a natural part of learning. Students should feel safe asking questions and seeking help when needed. By building trust and rapport, teachers can ease anxiety and boost students' confidence in their math abilities.

Another key factor in lowering the level on anxiety is incorporating hands-on activities and manipulatives to make math concepts more concrete and engaging (Cheung et al., 2023; Foulkes et al., 2023; Moore & Rimbey, 2022). For example, use counting blocks, puzzles, maps, or interactive apps to illustrate mathematical ideas. These tactile experiences can make abstract concepts easier to grasp and help students develop a deeper understanding of math.

Students need to be shown how math is relevant to their everyday lives. Teachers can create learning scenarios starting from day-to-day life activities. Incorporate real-world examples and applications of math concepts. This can help students see the practicality of math and motivate them to learn. For instance, teach math through activities like budgeting, measuring ingredients for a cooking lesson, or calculating distances on a map.

Also, teachers need to encourage a growth mindset in students by enchasing their efforts and perseverance rather than just their achievements. This strategic approach takes off the burden of assessment. This mindset shift can help students approach math challenges with greater resilience and less anxiety.

Also, a key factor is introducing technology in tasks, learning processes, assessment moments and teaching concepts. In building the strategic path to fulfill educational aims, teachers need to have a helicopter view over the math content and, in strong relation to the competences set for a specific grade, they need to sense the moment where technology can spice up learning (Higgins et al., 2017).

Last, but not least, lets always remember the benefits of play when involving children in educational processes. Playful activities make learning math enjoyable and engaging. When students associate math with fun and excitement, they are more likely to approach it with enthusiasm rather than anxiety. Playful experiences can ignite their curiosity and passion for the subject.

Further, the article presents a possible procedure to create effective scenario-based math activities using robots as didactic material in a strategy that aims to reduce anxiety.

3. Research methodology

3.1. The research design

The aim of this research is to show how educational robots can act as catalysts for effective mathematics learning when using scenario-based activities.

Two questions contour this article:

1. How can teachers create effective scenario-based math activities to reduce anxiety?

2. What are the key pedagogical elements in designing and implementing scenario-based math activities using robotics?

3.2. Participants

In this study, the expertise of 23 primary school teachers was used in the creation and testing of scenario-based activities aimed at enhancing mathematics learning with the assistance of educational robots. To begin, a diverse group of experienced primary school educators was selected, representing various grade levels and teaching backgrounds.

3.3. Procedure

The teachers were actively engaged in the design phase, where they collaborated with the researchers to develop scenario-based mathematical learning activities tailored to their specific grade levels and curricular goals. These activities were then integrated with educational robots, serving as interactive learning tools. Subsequently, the teachers facilitated these activities in their classrooms, allowing researchers to observe and document the implementation process. Post-implementation feedback sessions were conducted to gather insights, suggestions, and critiques from the teachers, which were instrumental in refining and fine-tuning the scenario-based activities. This collaborative process ensured that the activities were both pedagogically effective and practical for real-world classroom settings, highlighting the valuable role of primary school educators as co-creators and testers in the development of innovative educational tools for mathematics instruction.

In the design phase the following path was taken:

1. Extract specific competences from the curriculum;

2. Recommend content to work on the extracted competences;

3. Connect the competences with the content through a pedagogical strategy that includes methods, resources and form of organizing students.

In order to create educational scenarios involving robots in the development of general mathematics skills, the age group and the school curriculum were taken into account. The school curriculum and the specific competences for each chosen activity were analyzed, the school curriculum is described on the basis of European recommendations on key activities following various national and international evaluations at primary education level.

The educational scenario involving robots as educational and cognitive learning material should contain basic elements describing the teaching process and learning activity and all the tools used for learning the content (Komis et al., 2017).

Such a scenario should be organized in such a way that it is a good guide for the whole activity that takes place in the course proposed by the teacher and carried out with students.

In order to develop the scenarios involving educational robots, the seven phases through which a scenario with educational robots must pass were taken into account (Komis et al.2013). These phases are independent and can be completed individually, but they take into account several specific features of preschool education.

The seven phases are:

- choosing the teaching topic;
- identifying the children's prior knowledge;
- setting the objectives;
- choosing the teaching materials needed to apply the robots;
- managing the teaching process; evaluating the scenario;
- documenting the scenario.

Taking into account the design phases of an educational scenario involving robots, each scenario consists of several mutually dependent components that are of major importance in their development.

A template was proposed for the scenario development consisting of the following components: title of the scenario, age of the children, time needed, content/topic, purpose of the activity, introduction, resources, detailed description of the scenario, steps, tips and tricks for the teacher, implementation of the scenario and other resources, variants of the scenario/game. Next, we will describe each component of the scenario in detail:

- The title of each scenario was chosen depending on the subject and the objectives proposed, each title should contain the key words of the activities to be carried out.
- The age of the pupils also matches the content chosen for the scenario. Scenarios were written for 6–10-year-old, the age corresponding to primary school pupils. Each script can be adapted for different ages, changing only the title and some details of the activity description.
- The time allocated may be different depending on the proposed activity, whether they are integrated activities within a lesson or whether they can be a single lesson only with the application of educational robots.
- Each scenario also contains a short introduction that describes a specially created problem situation, the solution of which depends on the completion of the proposed activity using the educational robots.
- Detailed description of the scenario, this is where the description of the scenario comes in, perhaps in the form of a story or formulated as a problem. The most important ideas to be taken into account by the children in carrying out the activity and in going through the steps to be described are highlighted.
- Steps, this component is the most important in the whole scenario, here the proposed objectives are achieved and the development of a computational thinking takes place through the realization of the algorithm described by the steps. Also at this level, new concepts will be taught or previously acquired knowledge will be applied to develop various necessary and mandatory skills for the appropriate age of the learner. By describing these steps and going through them some of the general competences will be

developed: identification of relations/regularity in the immediate environment; use of numbers in calculations; exploration of geometrical characteristics of objects located in the immediate environment, use of conventional yardsticks for measurements and estimations and for all scenarios the steps to reach the very important general competence of solving problems in familiar situations should be described. This component of the scenario is key to the main goal we are pursuing by applying educational robots in primary classes to the teaching of mathematics and aims to apply effective teaching and learning strategies in order to achieve the learning objectives through the use of an appropriate digital environment.

- Tips and tricks for the teacher, this component is not compulsory but it is important for the teacher, it contains some hints and tips just for teachers to get the best results during the realization of the proposed scenario, but also long-term results by achieving the proposed objectives and establishing a beneficial relationship between student and teacher by introducing technology in the training process and preparing the young student for future life situations.
- Scenario implementation and other resources, variants of the scenario/the game, the last component of the scenario which allows each author to add or remove named elements from the scenario. It is the component that allows to improve what is and to adapt the scenario for different levels of learner training.

For the creation of an educational scenario based on robots, appropriate learning content was designed to contain problem-solving situations, as well as teaching support for the learner in applying the practices of implementing programming concepts. This content has to be adapted to the investigation and problem-solving situations with further development situations, applying the acquired knowledge and experiences (Source Misirli, A., & Komis, V. (2014).

4. Results

In the design phase, five scenarios were tailored to their specific grade levels and curricular goals. All scenarios used robotics. The topics for the scenarios were: geometry, numbers, four operations, measurement, problem solving.

Scenarios were developed only for the following topics: numbers - identification of fractions, use of fractions in familiar contexts, age 9-10 years; numbers - recognition of numbers and association of a set, age 7-8 years; geometry - square, rectangle, triangle, circle: identification and graphing; four operations, age 8-9 years; problem solving - age 7 years.

For these topics or the following activities: analyses and describe spatial relationships, situating themselves in space in relation to others and objects; develop a basic understanding of estimating quantities and operations; learning outcomes: solve routine and non-routine problems with fractions; recognise basic multiplication/division facts using different strategies that mobilize number relationships and properties of operations; express mathematical ideas and processes, orally and in writing, using their own language and vocabulary.

Subsequently, the teachers facilitated these activities in their classrooms, allowing researchers to observe and document the implementation process. After this phase, the scenarios were refined and brought to their final version. In Appendix, one scenario is presented in details.

5. Discussions

During the process for designing and implementing the scenarios, researchers agreed on how crucial is for teachers to extract specific competences from the curriculum before any other task. This involves a deep understanding of the learning objectives and outcomes outlined in the curriculum. By pinpointing the exact competences related to mathematics, educators can ensure that their robotics activities are aligned with the educational standards.

Once the relevant competences are identified, teachers should recommend specific content to work on these competences. This content should not only be mathematically relevant but also engaging and suitable for integration with robotics. By carefully selecting content, educators can create meaningful and enjoyable learning experiences for their students.

Connecting competences with content requires a well-structured pedagogical strategy. This strategy should encompass various methods, resources, and ways of organizing students. Teachers must be creative in their approach, utilizing robotics as a tool to reinforce mathematical concepts. The pedagogical strategy should cater to different learning styles and abilities, ensuring inclusivity in the classroom.

The key pedagogical elements in designing and implementing scenario-based math activities using robotics gather in a priory structure for a scenario. At the core of scenario-based math activities is the concept of real-world relevance. The scenario should begin by introducing a relatable and engaging context that captures the students' interest. This context serves as the foundation for the math activity and should be chosen with consideration for the age and interests of the learners.

Next, the scenario should incorporate problem-solving challenges that require mathematical thinking. These challenges should be carefully designed to align with curriculum objectives and learning goals. They should encourage students to apply mathematical concepts and principles to solve practical problems encountered within the scenario.

Integration of robotics is a pivotal element in this approach. The scenario should feature robotics as a tool for exploration and experimentation. Students should have opportunities to interact with robots, program them, and use them as a means to collect data or perform tasks related to the scenario. This hands-on experience with robotics not only makes math tangible but also fosters computational thinking skills.

To ensure effective learning, the scenario should encourage collaboration and communication among students. Group work, discussions, and sharing of ideas should be facilitated to promote a collaborative learning environment. Encouraging students to work and play together helps them develop problem-solving skills and learn from one another.

6. Conclusions

The article presented the pedagogical approach on integrating the promising potential of educational robots for effective math learning. The two research questions have been thoroughly explored, leading to valuable insights for educators and researchers alike.

Our findings underscore the importance of scenario-based math activities as a means to reduce math anxiety among students. By immersing learners in real-world contexts and providing them with interactive, hands-on experiences through the use of educational robots, teachers can create a more engaging and less intimidating learning environment. This approach encourages active participation and problem-solving, ultimately fostering a positive attitude toward mathematics.

Furthermore, the identification of key pedagogical elements in designing and implementing these activities using robotics is of paramount importance. Through careful consideration of factors such as curriculum alignment, task complexity, and the incorporation of personalized learning pathways, educators can maximize the benefits of educational robots in math education.

As we move forward, it is evident that the integration of educational robots into math education has the potential to revolutionize the way mathematics is taught and learned. By addressing math anxiety and enhancing pedagogical approaches, we can create a more inclusive and effective math learning environment that empowers students to excel in this critical subject. This research not only contributes to the growing body of knowledge in the field but also offers practical guidance for educators looking to harness the power of educational robots in mathematics education.

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Appendixes

Scenario title/name of the game: Break the spell

Children’s age (primary school students): 7-8 years old

Time needed: 15 minutes

Content/Subject: Geometry (square, rectangle, triangle, circle: identification and graphic representation)

Aim of the activity: Analyze and describe spatial relationships, standing in space in relation to others and objects.

INTRODUCTION

This game involves describing the positions of objects in relation to other objects and associating objects with geometric shapes. Students are challenged to analyze the relationships between them and establish the path of movement of the object to the corresponding figure.

Resources:

Programmable robot or a toy: the robot is a small and programmable robot that moves in different directions and distances.

Shapes: circle, square, triangle, rectangle, different forms and image

Accessories: colorized scotch to make the table on the floor or a map divided in 15 cm squares or a map made of carton.

A DETAILED DESCRIPTION OF THE SCENARIO

An evil witch who went to bed late and didn't sleep. She was angry and grumpy so she turned the sun, pizza, TV and gift box into geometric figures! She then hid them among other objects! Only clever children can bring back the sun, the TV, the pizza and the gift box by guessing where each one is. Can we help? Let's see in what geometric figures the witch transformed the sun, the TV, the gift box and of course the slide of pizza? Let's break the spell!

STEPS

1. Students are instructed by the teacher how to use the robot and what is the subject of the lesson. Together they can name the robot as they wish.

2. They name the geometric figures given on the map, namely: the square, the triangle, the rectangle and the circle.

3. They associate the objects with geometric figures: the TV, the sun, the slice of pizza, the gift box (other objects can be chosen) – rectangle, circle, triangle, square.

TIPS AND TRICKS FOR THE TEACHER

Give instructions at the beginning of the game!

Encourage children to speak out loud when they think!

Each student makes mental maps or even notes of the sequences of instructions that the robot has to follow along the given route.

Repeat as a group the possible movements: left, right, forward, backward, rotate and if necessary, pause or reset.

Change the starting place of collecting the shapes, if you wish to add challenge for each participant!

Let children make mistakes. Trying again and discovering the error is part of the game!

Add in more shapes and more object to prologue and complicate the game.

The teacher can program the robot to congratulate or to encourage students to continue.

Play the game in teams to add competition, if you aim to increase the speed of solving the tasks!

SCENARIO IMPLEMENTATION AND OTHER RESOURCES

- Board or worksheet
- A robot
- An instruction sheet for the robot to be visible to students
- Stickers for rewords
- Small model sheet to pass the trails to the students

VARIANTS OF THE SCENARIO/THE GAME

More objects and geometric figure can be added (for higher grades).