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RESEARCH ARTICLE

Educational robotics and STEAM in early childhood education

Dimitra Chaldi[1*] **Garyfalia Mantzanidou**[2]

[1] Department of Medicine, University of Patras, Patra, Greece
[2] Kindergarten of Drepano, Koimiseos Theotokou, Drepano, Greece

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Correspondence to: Dimitra Chaldi, Department of Medicine, University of Patras, Patra, Greece;
Email: dimitrachaldi.speech@gmail.com

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Abstract: The interest in the future configuration, focusing on the innovative technologies and more specifically on STEAM (Science, Technology, Engineering, Arts, Math), is remarkably increased. The value of STEAM education is undeniable as a means of developing basic skills and competencies of young students improving the learning process, developing communication skills, and solving real-life difficulties. The current research study was completed in the context of an actual learning process, with the view to study educational robotics in kindergarten students to engage them with STEAM education, using the programmable robot Bee-Bot® initially. The didactic intervention was held, which was developed in two phases. More specifically, a sample of 12 children (age range: 5 – 6 years old) took part in an intensive educational robotics lab for 16 sessions (4 weeks) by using a bee-shaped robot called Bee-Bot®. The results of our current research study revealed that STEAM education could also take place in a speech therapy clinic using the appropriate educational robots. Our young students developed and mastered knowledge in programming and computerizing, and algorithmic thinking with playful mod using educational robots, and they also built their vocabulary and develop communication skills.

Keywords: STEAM, education robotics, kindergarten, programming, Bee-Bot®

1 Introduction

New educational technologies have been created in recent years to attract children to computer and computing activities (Duncan et al., 2014; Heljakka et al., 2019; Papadakis, 2021). Supporters of introducing creative thinking and problem-solving in education argue for systematic reform to primary and secondary schools that encompass modern technology educational tools demanded of students in the twenty-first century (Karakoyun & Lindberg, 2020; Papadakis, 2021; Vlasopoulou et al., 2021). Using and teaching with robotics has been increasingly studied in recent years, as research data have shown practical recommendations and positive results for students and teachers (Caballero-Gonzalez et al., 2019; Tzagkaraki et al., 2021). The possibilities of free expression, experimentation, and creation are given to toddlers when involved in the learning process. Educational robotics manage to combine learning through play, so education is easily transformed into a fun procedure, as it is widely known that learning is done easier, faster, and more effectively when is combined with play. Robotics can be an educational tool that arouses the interest and the curiosity of young kids using enjoyable activities in an attractive learning environment (Eguchi, 2010).

Over the last few years, increasing attention has been focused on developing children's acquisition of 21st-century skills and digital competencies (Nikolopoulou & Gialamas, 2015; Papadakis & Kalogiannakis, 2020a). Consequently, many education scholars have argued that teaching technology – the "T" in STEM (Science, Technology, Engineering, and Mathematics)– in young children is vital in keeping up with 21st-century employment patterns (Noh & Lee, 2020). When used intentionally and appropriately, technology and interactive media are practical tools to support learning and development (Donohue & Schomburg, 2017). In early childhood, new interactive and smart screen technologies create opportunities to enhance young children's growing, learning, and playing (Bers, 2008). Technologies, such as those involving robotics or coding apps, come when the demand for computing jobs around the globe is at an all-time high while its supply is at an all-time low (Glezou, 2020). At the same time, researchers and scholars have highlighted the vast cognitive benefits of introducing Computational Thinking (CT) skills to young children (Bertel et al., 2019; Papadakis & Kalogiannakis, 2019). Children as young as four years old can learn foundational computational thinking concepts, and this kind of learning can support their language, mathematical, cognitive, and socio-emotional development (Papadakis & Kalogiannakis, 2017).

The researcher who prompted robotics to be incorporated into education as an educational tool was (Jonassen, 2000), who argued that technology could be thought of as a computer-based tool that supports critical thinking and helps students learn efficiently. According to the international bibliography, researchers have found out that "instructional robotics" allows learners to be led into a learning situation by controlling the behavior of a model robot as it engages them in "experimentation, research, and problem-solving" (Alimisis, 2013; Sullivan & Bers, 2016). Pugnali, Sullivan, and Bers's (2017) research showed that students using robotics learn programming and encounter new concepts related to objects in their daily lives and with which they are in constant interaction. Kim et al. (2015) indicate that the contact and use of educational robots in education are significant and influential in teaching STEM. Educational Robots can improve cognitive and learning abilities in preschool children (Di Lieto et al., 2017). Educational Robotics can be considered a multidisciplinary approach involving aspects as diverse as design algorithms, mechanical design structures, construction, and operation of robots and robotics kits, and the possibility of applying engineering mathematics, physics principles, and other science subjects (Papadakis, 2021). In general, these characteristics and methods are very well suited for designing activities with STEM orientation (Chatzopoulos et al., 2021). Educational robotics has many real-world applications in science, mathematics, and engineering, helping to remove the abstractness of these scientific fields while improving skills and effective learning strategies such as spatial ability, selective attention, risk-taking, decision-making skills, *etc*. (Papadakis, 2020b). Especially, robotics technologies offer opportunities for children and young people for a practical, hands-on understanding of the things they meet in their daily life but do not fully understand, such as proximity sensors, motion detectors and light sensors [19], reasoning failures (software bugs) and connection problems (Wi-Fi, Bluetooth disconnection) (Vidakis et al., 2019).

Many researchers and educators agree that inclusion in primary education, Natural science, Technology, Engineering, and Mathematics provides a strong motivator and improves learning speed (Scaradozzi et al., 2015). Mechanical constructions in the form of robotics were first used by students in 1960 and are an effective technological tool that facilitates STEM learning. The STEAM educational model is derived from the idea of teaching in five areas: Science, Technology, Engineering, Art, and Math – helps children understand how the world around them works, stimulates children's creativity based on cooperation and teamwork. This model has been recognized, especially in developed countries, successfully and effectively implemented (Margot & Kettler, 2019). Educational robotics can consider one of the newest trends in education, and they have been introduced into classrooms ranging from kindergarten through high school to enrich the learning environment and promote knowledge-building activities (Papadakis, 2020a).

Many of children's everyday activities use STEAM skills. When children play, they explore and build skills. When they investigate their environment, they investigate, discover, and solve problems. Children are natural scientists while they try to figure out how the world works. Children create theories to explain what they see. Like scientists, children learn from others. They watch what children and adults do and learn from trying to repeat what they have seen. T is for technology that includes simple tools such as wheels, levers, and scissors. They support children's cognitive development. E is for Engineering, meaning using materials, building, designing, helping them understand how things work. A is for Arts meaning that children engage in drawing, painting, play, music. M is for Math, meaning numbers, patterns, geometry. When a teacher asks, "Which one is bigger / smaller / heavier / lighter?" children measure, estimate, describe. In conclusion, STEAM is all around us.

There are multiple advantages concerning using these devices in the learning process, including stimulus, motivation, ease of use, availability, connectivity, among others (Kim et al., 2021). Stoeckelmayr, Tesar, & Hofmann (2011) used a group of infants and designed sequencing and repetition activities with the programmable robot Bee-Bot®. They concluded that self-confidence and self-esteem, and interest in robotics were enhanced. Falloon (2016) stated that "Young learners learn basic coding by developing skills such as decomposition, problem analysis, and evaluation, which are important components for problem-solving." Programming gives children the tools to create and participate in a culture and working world structured by new technologies. In Greece, research has also been carried out on the potential of young pupils to develop their programming skills (Fesakis et al., 2013; Mantzanidou, 2019).

The purpose of this study is to explore the use of educational robotics in preschool students as a means of engaging them with STEAM education which is a modern and innovative teaching approach that utilizes five disciplines: Science, Technology, Engineering, Arts, and Mathematics as educational robotics is a tool for developing computational thinking, coding, engineering, programming, technology that are increasingly considered inextricably linked to STEAM education. The researchers choose a meaningful learning context for the students (Christmas Story). The engagement with educational robotics in the classroom was an inducement as it is widely accepted that children are interested in robots. In this case, the study that carried out in a public school, the following were analyzed:

(1) Research question 1. Can preschoolers (aged 4 – 5 years old) operate, program, and control an educational robot?

(2) Research question 2. Can educational robots support STEAM education and lead to new ways of learning?

2 Methodology

The purpose of the research is to investigate the use of robotics as a means of engaging with STEAM in kindergarten, and therefore the qualitative method is considered the most appropriate for the intended purpose, as the research questions are open and general questions, which need an answer during the study (Cohen et al., 2002). The qualitative method is commonly used in the humanities and social sciences, anthropology, education, *etc*. We chose to use a qualitative method instead of a quantitative method because we cannot select writing data from preschoolers as they do not know how to write yet (to write down their answers). The research was conducted in activities (classroom) in an urban public school in Patra, Greece serving students in kindergarten grade. One of the researchers was also the teacher of the class. The other researcher was a Speech and Language Pathologist who had permission from the teacher and parents to participate in this study and collect and analyze the data.

2.1 Research Tools

For the research during the first phase (Phase 1), data were collected from semi-structured interviews (SSI) of the students through a questionnaire with ten (10) open-ended questions that lasted ten (10) minutes to discover children's previous knowledge and audio recordings. During the second phase (Phase 2), the researchers developed scenarios and students' worksheets. Data were collected from the researcher's notes - diary, children's notes- drafts, the artifact of the pupils, semi-structured interviews of the students with open-ended questions, why and how questions, photo documentation, audio-video recordings during the testing activities, and direct observations informed consent forms signed by the parents. The interview questions on both phases were designed by the researchers and were based on previous research studies.

The data underwent a qualitative analysis. Twelve (12) students participated in the research, between 5 and 6 years old (mean age = 72.0 months), eight (8) boys and four (4) girls, and they have not been involved with educational robotics before. Each participant group was small (three children per group) to foster collaboration, communication skills, and teamwork. The Bee-Bot® was used as a learning support tool in a research-based practical way and contact educational robotics. All four groups took part in a half an hour session twice a week for four weeks. None of the children had been previously exposed to educational robots. The students were anonymized for data analysis: each student was assigned an anonymous code.

2.2 Data Analysis

After careful reading of all the research data collected and the active search for meanings, the researchers followed the open coding. An organized data file was created, on which the researchers relied to write the findings of their study. Subjects/topics were then sought so that the researchers could connect, understand, select, describe, and interpret the research material, followed by the creation of a thematic map that illustrated the meanings that existed throughout the research material. In this research context, national and international research ethics guidelines were followed, such as the guidelines suggested by Petousi and Sifaki (2020).

2.3 Bee-Bot®

Bee-Bot® is a colorful, simple-to-use programmable robot designed and intended to be used in preschools, elementary schools, and some therapeutic clinics worldwide. The use of buttons on its back makes its use in practice easy for children. This programmable robot was awarded as the most impressive hardware for kindergarten and lower primary school children on the world educational technology market (Scaradozzi et al., 2015). It is a Bee-shaped robot, yellow with controls to move forward/backward and turn left-right.

The Bee-Bot® is perfect for teaching simple programming concepts, controls, positional and directional languages, sequencing, understanding algorithms, debugging, estimations, and problem-solving. The Bee-bot can teach young children essential skills like logical thinking

(García-Peñalvo et al., 2016). The Bee-bot has a positive impact on students' problem-solving and metacognitive skills (Highfield, 2019). It can be used for the development of fine motor skills by using the directional buttons. It can support imaginative play and allows learners to prove skills in ways that a traditional approach would not support. Bee-Bot® programming is made by using onboard keys-symbols, and it can be programmed in the same way the Logo language "turtle" moves.

Bee-Bot® moves in steps of 15 cm and turns in 90° turns. Directional keys are used to enter up to 40 commands/instructions, which send Bee-Bot® forward, back, left (90°), and right (90°), start to move, and others. Pressing the green GO button starts Bee-Bot® on its way. Bee-Bot® blinks and beeps after each command to allow children to follow Bee-Bot® through the program they have entered and then confirms its completion with lights and sound. This qualitative research study has observed a particular problem with the CLEAR button several times. Before entering new instructions, the students shall clear the Bee-Bot® memory. Otherwise, previous instructions are saved, and by pushing buttons, the students will add new commands at the end of programming.

2.4 Phases – Activities

2.4.1 Phase 1

Before the robot presented to students, an eight-minute semi-structured personal interview by researchers was held to discover children's previous knowledge. Each student was moved to another classroom for the semi-structured interview as the researchers sought. The answers of their classmates should not influence the students' answers to their questions.

Interviews

The students were asked what a robot is and what it is not and answered what they think a robot is, what it is doing, and why they believe. Consequently, the students had to choose from a series of images of what they consider to be robots and justify their answer (the researchers asked the students: how they recognize a robot), how robots work, move, if they know the components with which a robot is made up if play with the Lego bricks, and if they know the Bee-Bot®. The researchers introduced the Bee-Bot® robot into the teaching activities to introduce the students to programming and robotics in a playful way. The following activities included programming concepts such as sequence and repetition. The students were taught the basic concepts of the programming language playfully. Their interest and curiosity were stimulated and established correlations between programming and everyday life. The whole procedure lasted 1 hour and 30 minutes.

2.4.2 Phase 2

In Phase 2, three teaching sessions were held. During the second phase, data were collected through a questionnaire, audio recordings, and direct observations.

1st Session: Robot people

In the first session, the students were engaged in experiential activities, programming concepts such as sequencing, and repetition to get involved in the programming process and think pleasantly and entertainingly. Specifically, they were asked to program a peer (movement sequence) with a role-playing game from when he wakes up in the morning to prepare and go to school (Science).

In practice, they found that when they did not give the correct instructions, their classmate went to school barefoot or with pajamas, etc. After some efforts, they identified "their mistake" and programmed their peer correctly (Time taken 45 minutes) (Mantzanidou, 2019). The students also "programmed" their peers to move forward, backward, left, and right. The learning goals are the students' familiarization with the robotic systems, their understanding of programming, running the program, and choosing the best route.

2nd Session: Investigate the robot

In the second session, the researchers presented the programmable robot (Bee-Bot®) to become familiar with the Educational Robot and explore its distinct parts (Technology). Research topics included: "Give commands to the robot to move to your friend," "Can you give commands" to "the robot to turn right/left?", "Can you give orders to the robot to move further from your friends " (Math), "how can you plot a route on a paper for the robot"? The students became acquainted and experimented with the Bee-Bot® symbols to learn how to correct commands, properly program the robot and understand its steady pace (15-centimeter range of motion). Twisting the Bee-Bot® constituted the biggest challenge as they understood that "turn right or left" means that it literally turns right or left and does not move forward or sideways (learning from experimentation and mistakes). Consequently, the students got familiar with the symbols-keys of Bee-Bot®. To record their thoughts, they were asked initially to plot a route on paper and then, in practice, program the robot with the route they planned, so they record their algorithm by drawing the command symbols on a sheet of paper.

Students had the opportunity to collaborate, experiment, and program the Bee-Bot® by engaging in various activities. During the experiment, they forgot to use the command "clear," so the robot had to make all the moves from the beginning. The students took part with enthusiasm, following the given instructions from the researchers to program the robot on a specific route and the execution of explicit instruction (Time taken 60 minutes). (see Figure 1)

Figure 1 Plotted route on the paper

3rd Session: Designing STEAM curricula with Bee-Bot®

This curriculum focuses explicitly on the technology, engineering, math, and art components of STEAM. In this activity, researchers asked students to search the web using the interactive board and found images/paintings (Arts) related to the story of Jesus Christ's birth. They selected and printed some of them. The first research question was: Can students create a square grid mat with pictures for the robot can move on it? Students create a square grid mat that they designed using the ruler so that the robot could make a 15 cm (Math) step at a time. The second research question was: Can students draw and built a manger? Students draw the manger with a Christmas tree (Arts) and "built" one with Lego bricks (Engineering sturdy construction). (see Figure 2)

Figure 2 Building the manger

The engineering design process refers to the iterative process engineers use to design an artifact to meet a need (Bers, 2008). Students engage in examining engineering concepts in kindergarten through building and designing with craft materials, recycled materials, and LEGO bricks (Sullivan & Bers, 2016).

The first research question to the pupils was: "Can you program the Bee-Bot® to follow the Nativity Story?" The teams used the square grid mat and the Bee-Bot® robot to narrate the story.

Educational robots play a significant role in the development of digital competencies related to programming. Each team had to program the robot to follow a particular path. The third research question was: Can students program the BEEBOT to move from a start point to the manger, but it has to stop for 30 seconds to the Angel and the Star? The teams programmed the robot to move from a starting point to an endpoint, following routes and stopping at intermediate positions (i.e., Angel, Star).

The fourth research question was: a) to direct the robot to go to the manger, but it has to avoid Herodes Palace (in this activity, restrictions were added, so through play, students deal with challenges and develop their problem-solving skills), b) to direct the robot to go from the three wise men to the star but stopping it for a minute (mathematical thinking) to Herodes palace, c) to direct the robot to go to the manger but there was a restriction students had not to use the left command. Eight progressively difficult levels were included, with a timer and stars awarded. Students examined the program's efficiency during programming to decide if it was effective while investigating different solutions to make the required changes (i.e., critical thinking, problem-solving). We also must mention that in all activities, students did not use command cards. Students also draw the robot's path on paper in all activities. (see Figure 3)

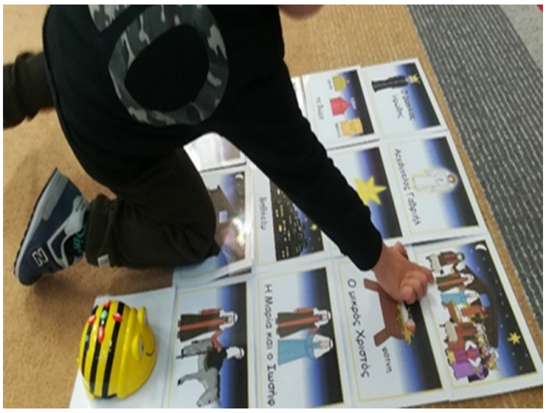

Figure 3 Square grid mat

Two teams faced difficulties turning the robot, but after some efforts and support from the other teams, they successfully managed to program the robot to follow the commands. Eventually, all teams managed to follow 12 commands. Students developed skills to dissect, understand, and analyze problems that they encounter during the activities. They were concentrated during the programming while having fun. Something that adds particular interest to the research is that the students were not given any command - keys (cards) or explanations that would help them program the robot. When they made a "mistake," the researchers preferred to observe the activity without adding or removing command cards.

Students got familiar with Programming (i.e., sequencing, building algorithms up to 12 commands, loops), Technology, Mathematics (i.e., concepts of distance, motion, orientation, measurement, time, turns, space, problem-solving), and Arts.

2.5 Interviews

The students were asked what a robot is, is doing, and why they have that opinion. Consequently, the students were asked to describe the Bee-Bot® robot, plot a route on paper, program the Bee-Bot® robot (give commands), and describe how they can design and build a sturdy construction.

Qualitative evaluation

The qualitative research technique of semi-structured interviewing is commonly used in psychology, educational science anthropology, and others. The researchers conducted two semi-structured interviews, one at the beginning of the project and the other at the end, to collect qualitative data and get positive and negative feedback. The interviews took place at the school. The first questions dealt with background information, as well as earlier knowledge in the field of robotics. The second interview dealt with what the pupils learned. This qualitative evaluation aimed to find out what interviewees think about knowledge gained, programming, STEAM, teamwork, and the impact of using a robot as a pedagogue's tool to teach programming and Steam.

3 Discussion and Conclusions

The target of the study was to familiarize the students with robots and STEAM as New Technologies and robotics develop rapidly. About the 1st hypothesis, the results of this study (second and third session) display that those students can manage, program, and control a programmable robot. According to the data collected at the end of the first and second phases and on the second interview, the students managed the Bee-Bot®, got familiar with programming commands even though they did not use command cards to help them. The study shows the impact of educational robots in the development of digital competencies related to programming (García-Valcárcel-Muñoz-Repiso & Caballero-González, 2019).

As far as the second hypothesis that Educational Robots can support STEAM education and lead to new ways of learning is concerned, based on the findings of the interviews and direct observation, the students got familiar with the parts of the educational robot (Technology), understood of Engineering as they described step by step, designed and built the manger. Students grappled with Math conceptions of distance, orientation, turns, measurement, and sequencing. Kindergarten students also engage with Arts by drawing and painting the manger. The study shows the positive impacts of the insertion of educational robots (in this study Bee-Bot®) to boost the development of abilities and concrete interests of kindergarten children associated with STEAM education.

This didactic intervention to examine preschool students' involvement in STEAM through educational robotics, particularly with the Bee-Bot® programmable robot, showed that STEAM education could be accomplished in kindergartens. Our study shows that using an educational robot-like Bee-Bot® in a kindergarten classroom is more than a coding lesson. It introduces students to STEAM. Educational robots, subject to proper didactic intervention taking advantage of the nature of kindergarten children for research, expression, discovery, construction, contribute to their contact with STEAM education. Simple Educational Robots (Bee-Bot®) dynamics teach basic programming concepts such as sequencing, algorithms, debugging, prediction, decomposition, and math (concepts of distance, motion, orientation, measurement, time, turns, space) problem solving, were tested. Students built programming skills and developed computational and algorithmic thinking skills. Students were very enthusiastic about "playing" with the Bee-Bot® even though at the beginning, they faced difficulties in programming the robot to turn right /left. They also had difficulties with the Clear button and sequencing.

Based on the feedback from qualitative analysis, educational Robots familiarize students with Physics, Engineering, Technology, Mathematics, Science, Arts playfully and creatively and can effectively support STEAM education and lead to new ways of learning. Teachers can foster children's development of STEAM skills by providing teaching opportunities and appropriate materials that support exploration and discovery.

Using appropriate and well-designed educational activities based on modern learning theories, educational robots can be a practical educational tool in kindergarten and elementary school. We highly recommend the use of educational robotics in kindergarten as an innovative learning environment, which supports the students to develop knowledge and abilities, which will lead them to learn how to solve problems, enhancing at the same time, teamwork, collaboration, critical and computational thinking, creativity, their fantasies and engagements with STEAM education.

4 Limitations and future work

The introduction of STEM education, specifically the implementation of educational robotics (ER), has drawn researchers' attention and has shown that teachers play a crucial role in leading this innovation (Papadakis et al., 2021). Although the potential positive impact of technological tools such as tablets and robotic kits on learning in schools has been widely acknowledged, more research is needed to explore in-depth the teachers' perceptions of the impact of robotic kits in learning in preschool education (Papadakis & Kalogiannakis, 2020b), and how these perceptions could influence the use of these tools in the learning process. Nowadays, young children can build their robot, program it to do what they want, and decorate it with art supplies (Sullivan & Bers, 2018). Thus, in the education sector especially, today's question is how children will be enabled to use digital technology in a way that best benefits them (Demetriou, & Nikiforidou, 2019; Papadakis, 2020b). For instance, (Mantzanidou, 2019)Yelland (2011) highlights that children often come to their early learning service with knowledge of technology that may be unfamiliar and even intimidating for their educators.

On the contrary, a lack of technical knowledge and support has been identified in the relevant literature as a potential challenge for teachers implementing robotics in their classroom

(Papadakis et al., 2021; Urlings et al., 2019). As such, educators must think carefully and critically about how their beliefs and confidence with technology influence what they choose to integrate and how their choices can best align with children's social and cultural experiences (Papadakis & Kalogiannakis, 2019). Based on the results of this case study, future research is needed, as these results cannot be generalized due to the small number of students. Future work with larger sample sizes is needed to collect generalizable results. Moreover, to support the internal and external validity, researchers could also involve young students in the robotics association and the application of STEAM at any other time and in elementary school.

Conflicts of interest

The authors have no conflict of interest to declare.

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Human rights statements and informed consent

All procedures followed were following the ethical standards of the responsible committee on human experimentation. Informed consent was obtained from parents for being included in the study.

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