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RESEARCH ARTICLE

# Marine plastic pollution in kindergarten as a means of engaging toddlers with STEM education and educational robotics

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**Abstract:** In recent years, education has increasingly focused on children's acquisition of digital skills and abilities, which leads to the need to create new educational methodologies capable of engaging students in computational thinking activities. The research interest of this paper focuses on how preschool children can be more involved in STEM and educational robotics through authentically experiential learning on the topic of marine plastic pollution. It examines toddler engagement through an integrated STEM scenario using the programmable robot Bee-Bot and encourages children to solve problems in many possible ways, assessing the strengthening of their necessary skills. The teaching intervention took place during the 2021-22 school year in a Kindergarten in the city of Ioannina. During the planning and implementation phase of the program, action research and field study are applied, while the sociocultural approach to teaching natural sciences, educational robotics, new technologies, engineering, the arts and mathematics. The research framework is completed with the evaluation process and the students disseminating the project learning outcomes.

**Keywords:** STEM, educational robotics, BeeBot, marine pollution

## 1 Introduction

In recent years, education has increasingly focused on children's digital skills and abilities (Skaraki, 2021; Papadakis & Kalogiannakis, 2020), which leads to the need to create new educational technologies capable of engaging students in computational thinking activities (Papadakis, 2022). Introducing Computational Thinking (CT) skills to preschool children confers enormous cognitive benefits (Papadakis & Kalogiannakis, 2019) and can additionally support their language, mathematical and socio-emotional development (Katsaris & Vidakis, 2021; Papadakis & Kalogiannakis, 2017).

Many researchers and educators agree that including STEM (Science, Technology, Engineering and Mathematics) in primary education provides strong motivation and improves learning speed (Scaradozzi et al., 2015). The STEM educational model stimulates children's curiosity and creativity and helps them understand how the world around them works based on cooperation and teamwork (Margot & Kettler, 2019). Technology, the T of STEM, adheres to 21st-century employment patterns (Noh & Lee, 2020) and practically supports learning and teaching (Chaldi & Mantzanidou, 2021; Donohue & Schomburg, 2017).

Educational robotics, one of the newest trends in K-12 education, enriches the learning environment through knowledge-building activities (Papadakis, 2020a; Foti, 2021), as research data has shown positive outcomes for students and teachers (Tzagkaraki et al., 2021). Through play and in an attractive learning environment, educational robotics arouses the curiosity and interest of young students and turns into a practical and fun learning tool (Eguchi, 2010; Tsoukala, 2021).

This research studies the use of educational robotics in preschool students to engage them with STEAM education on the global problem of marine plastic pollution. A meaningful learning context for toddlers (an environmental story) was used.

## 2 Theoretical approach

### 2.1 STEM definition

The term STEM was introduced in 1990 by to National Science Foundation (NSF) as an acronym for Science, Technology, Engineering, and Mathematics (Bybee, 2010) and is an approach that aims to integrate Technology and Engineering into the teaching of Physics of

Sciences and Mathematics (Kalogiannakis & Papadakis, 2020; Peglidou, 2014). This acronym is also used as a definition of STEM education, recognizing STEM from the individual fields that make it up, and as a general description of any educational policy that refers to one or more STEM fields (Bybee, 2013).

Considering the failure of the traditional teaching of the separate subjects of science, mathematics and technology, the new approach, known as STEM (Science, Technology, Engineering & Mathematics) (Kastriti et al., 2022; Strataki, 2022), also attempts to introduce these concepts from an early age. The STEM approach is defined as a total of the following (National Academy of Engineering and National Research Council, 2009):

(1) Science concerns knowledge based on studying the surrounding world and nature's laws.

(2) Technology concerns the application of this knowledge in everyday life.

(3) Engineering is both the knowledge and the process of solving problems (design under specific constraints, such as the laws of nature, time, money, available materials, environmental regulations, etc.).

(4) Mathematics studies patterns and relationships between quantities, numbers, and shapes.

These scientific fields intertwine creatively, as Engineering uses concepts from Science and Mathematics and technological tools (Papadakis et al., 2021; Skaraki & Kolokotronis, 2022). The NSF also describes the term STEM in a broad sense as " *the totality of the sciences (physics, biology, geology, atmospheric and ocean sciences), mathematics, statistics and ICT, social, behavioural, and economic sciences, as well as all aspects of engineering and technology"* (NRC, 2011).

Recently, it has been proposed to utilize Art in STEM education, to enhance students' creativity and innovation, thus creating the interdisciplinary STEAM (Science, Technology, Engineering, Art & Mathematics) (Stemtosteam, 2022).

Effective STEM education should capitalize on students' initial experiences and interests and build new knowledge on top of what they already know without forgetting that students should acquire holistic development through interesting science practices (NRC, 2010). (see Figure 1)

**Figure 1** STEM and robotics

## 2.2 Learning theories and STEM

The theoretical, conceptual framework of STEM Education is based on Piaget's constructivism, Vygotsky's social learning theory, Papert's constructivism and Bruner's discovery learning theory.

The theory of constructivism (or constructivism) is based on the view that the student constructs new knowledge through new experiences and an effort to integrate the new information into his cognitive potential. Students learn by actively building new knowledge on pre-existing knowledge through communication with their environment (Mavropoulos, 2004). Finally, Piaget argued that education does not aim to increase students' knowledge but should seek to give the child the opportunity to discover, invent, and learn how to learn (Mavropoulos, 2004).

Vygotsky, a supporter of the sociocultural theory, argues that development is directly related to social interactions, is a product of social interaction, and its primary purpose is to provide children with the appropriate "tools" and means that will help them in the transition of thinking from social level to the individual (Doliopoulou, 2004).

Discovery learning was advocated by Bruner and is based on the view that students discover principles or develop skills through experimentation and practice, and the knowledge students gain in this way is more effective and lasting than simple memorization (Papadakis, 2021). The role of the teacher is pivotal since he must create the appropriate conditions where discovery will increase (Dimitriadis, 2014).

Seymour Papert (1928-2016), a supporter of constructionism (constructivism), developed his model for learning using Piaget's theory and theories of artificial intelligence, as he was effectively at the centre of three revolutions: the "development of a child", of artificial intelligence and computing technologies in education (Kalogiannakis & Papadakis, 2007). According to Papert, as for Piaget, learning is not transferred from the teacher to the student but is an active process built by the child (Komis, 2004). Papert extends Piaget's ideas about constructivism in education by promoting the view that learning is most effective when students are activated by constructing tangible objects in the real world that are meaningful to them. According to Papert, such frameworks are created and offered through computational Microcosms (Dimitriadis, 2014).

## 2.3 Methodologies for integrating STEM into teaching practice

Integrating STEM into everyday practice requires two kinds of methodological approaches, active and dynamic: a) teaching through inquiry and b) applying engineering principles.

(1) The European Commission in 2015 suggests inquiry-based teaching as one of the most effective 21st-century skills. This methodology is suitable for young students, but with some adjustments. Inquiry always starts with questions, but since it is often not possible to investigate them, the role of the teacher is catalytic to help students focus on observation and clarify the questions. Young learners should first engage and wonder, which means they should be given time to play in an environment shaped by rich scientific stimuli (Chalufour & Worth, 2004).

Martin-Hansen (2002) distinguishes three types of questioning:

(a) Centred, open-ended inquiry, which begins with a student question, followed by a student group design of inquiry;

(b) A guided inquiry that begins with a teacher question and targets a specific concept, idea, or pattern;

(c) Questioning is in pairs, which is a combination of guided and open questioning.

(2) In the case of engineering design, problems have more than one correct solution (open-ended problems). Moreover, they are always associated with certain limitations and specifications. Through engineering, students realize that math and science are relevant to their lives, as engineering activities are based on authentic, real-world problems around them. Through engineering, students are asked to apply what they have learned in science and mathematics; their learning is enhanced.

An engineering design methodology is a cycle with no starting or ending point. It has the following stages:

(1) definition of the problem /I ask;
(2) information gathering /I imagine;
(3) production of multiple solutions / Design;
(4) analysis and selection of the most appropriate solution /Create;
(5) checking and testing this solution /Test and Improve;
(6) Apply the /Share solution.

Engineering activities decriminalize error in the classroom and remove the stigma of failure. Instead, failure is an essential part of problem-solving and a positive way to learn. There is no single "right" answer in engineering, as a problem can have many solutions. When classroom instruction includes engineering, all students can identify themselves as successful. When students work together to answer a question, they collaborate, think critically and creatively, and communicate with each other. The teacher can develop inquiry activities during or after the planning process, but the solution must include constraints. Additionally, students must justify their design with scientific arguments and propose improved versions based on existing knowledge (Thulin & Redfors, 2016).

## 2.4 Reflection

All methodologies involve reflection, an implicit process every time we reuse our ideas. It includes retrospective and prospective self-evaluation processes, where our progress is analyzed against goals or next steps. It is essential to encourage and support reflection, and teachers should spend time on this activity (it can be done individually or in groups, through open or closed activities) (Thulin & Redfors, 2016).

## 2.5 Cooperation

An essential element of STEM integration in teaching and learning is collaboration. It differs from collaboration in that it focuses on participation, intellectual interdependence, and co-construction of knowledge, having shared standards of accepting different points of view to reach a common consensus. In contrast, collaboration emphasizes the division of labour and individual contributions, which are then synthesized into an everyday product. Integrating STEM approaches requires cooperation between children and teachers, who should support the process by creating a "bridge" between the child's previous experiences and the focus of new knowledge (Thulin & Redfors, 2016). (see Figure 2)

**Figure 2** Experiment: Cleaning up the sea from an oil spill

## 2.6 STEM in kindergarten

There is an undeniable connection between early childhood and STEM. Early exposure to STEM, in any way, results in children's academic growth, critical thinking and reasoning skills development, enhanced interest in later STEM studies, and better career prospects (Chesloff, 2013). Young students are born scientists, researchers, and engineers (Stone-MacDonald et al., 2011). Research shows that high-quality early childhood education boosts entry into higher education by 80% and employment by 23%. It also appears that children's attitudes towards scientific concepts and science learning are essentially formed in the early years of their education and become difficult to change once children reach adolescence (Archer et al., 2010). According to the latest views on brain development, Kindergarten can be the place to start emphasizing STEM education to have positive results in the future (Torres-Crespo et al., 2014). The literature gradually supports the importance of STEM education at young ages (Torres-Crespo et al., 2014).

## 2.7 Educational robotics in kindergarten

Educational robotics is considered one of the newest educational trends and has been introduced to all levels of education, enriching learning and promoting knowledge-building activities (Papadakis, 2020a). It concerns an interdisciplinary approach that includes many different aspects (algorithms, robotics kits, mechanical design, construction and operation of robots, principles of physics and other sciences, etc.) (Papadakis, 2021), finding application in all fields of STEM (Chatzopoulos et al., 2021).

According to Eguchi (2014), educational robotics can be integrated not only into STEM activities but also into many other school subjects, such as literacy, social studies, dance, music, and art, while offering the opportunity for children to work in groups, to express themselves through technology, cultivate collaborative skills, solve problems, and think critically and innovatively.

Educational robotics is based on constructivist theory and has many real-world applications in science, mathematics, and engineering, helping to remove the abstract nature of these scientific fields while simultaneously improving skills and effective learning strategies such as spatial ability, selective attention, risk-taking, decision-making skills, etc. (Papadakis, 2020b).

## 2.8 BEE – BOT

Bee-Bot is a yellow, easy-to-use, programmable bee-shaped robot with buttons on its back, designed and intended for young children in Kindergarten or early elementary school. This floor robot was awarded as the most impressive material for Kindergarten and elementary school children in the global educational technology market (Scaradozzi et al., 2015).

Bee-bot can teach young children basic skills such as logical thinking and is ideal for teaching simple programming concepts. Bee-bot positively impacts students' problem-solving and metacognitive skills (Highfield, 2019). (see Figure 3)

## 2.9 Marine plastic pollution

In recent years the seas of our planet are in danger of turning into "plastic traps" for us and the extraordinary life they host. These result from the data released by the Hellenic Center for

**Figure 3** BeeBot

Marine Research (EL.KE.TH.E.) with the completion of the competitive European program "CLAIM" (Cleaning Litter by developing and Applying Innovative Methods in European Sea), financially integrated in Horizon 2020, appears that if we do not change habits immediately, by 2050, there will be more plastics in the sea than fish. More specifically, nine million tons of plastics leak into the oceans yearly. It is even estimated that 11,500 tons of plastics end up in the Greek seas yearly. Furthermore, everything that "ends up" in the sea does not stay there but returns to our bodies through the food chain, with each of us unintentionally consuming 5 grams of microplastics per week. The EL.KE.TH.E. estimates that 90% of beach litter is of plastic origin, with straws and bottle caps dominating. Plastic waste poses a serious risk to marine ecosystems, biodiversity, and human health and affects essential activities such as tourism, fishing, oyster farming and fish farming (https://www.wwf.gr/ti_kanoume/anthropos/plastika/). (see Figure 4)

**Figure 4** Save the seas from plastics

# 3 The learning framework

The implementation of the integrated STEM teaching and learning of the present scenario is facilitated using specific pedagogical approaches (Project-based and problem-based learning-PBL, Inquiry-based learning-IBL, interdisciplinary learning, emphasis on STEM topics and skills, continuous assessment, collaboration with Agencies, teacher professional development, school leadership, access to technological equipment, high-quality teaching materials - BeeBot, etc.). Students are divided into small, heterogeneous groups of 3-4 people via a digital name wheel Random Name Picker (https://wheelofnames.com/el/), which remains constant throughout the execution of the script.

## 3.1 Goals

At the end of the scenario, students are expected to be able to:
(1) To raise awareness about sea pollution;
(2) Learn to search for information online safely;
(3) To realize the importance of receiving information from expert scientists;
(4) Engage in STEAM Education activities;
(5) To think about how technology can be a solution to real-life problems;
(6) To acquire 4 Cs skills (collaboration, communication, creativity, and critical thinking);

(7) Acquiring 21st-century skills (technological, IT, and media literacy).

## 3.2 $1^{\text{st}}$ Phase: Sensitization of students and awareness of fundamental problems of everyday life

The teacher presents the topic to the students, who are asked to talk about their experiences on the topic. Students are asked the following questions:

(1) Have you ever seen plastic waste in the sea? What kind?

(2) Would you like to swim in a polluted sea?

Then watch some of the following videos that are relevant to the topic:

(1) https://www.youtube.com/watch?v=-xuVHJ_uSAo;

(2) https://www.youtube.com/watch?v=kWXpPFK5Lbs;

(3) https://www.youtube.com/watch?v=FbKv9E2Djso;

(4) https://www.youtube.com/watch?v=xy7eZNao_eA;

(5) https://www.youtube.com/watch?v=QVGSpwWOcQ4;

(6) https://www.youtube.com/watch?v=WmWXmaPcozA;

(7) https://www.youtube.com/watch?v=reFuAx9pDCI;

(8) https://www.youtube.com/watch?v=TgSrwKoCxKE.

Nevertheless, students and teachers exchange opinions about the content of the videos they watch. The students are asked the following questions, and the discussion begins:

(1) What did you think and feel when you watched the videos?

(2) How do you think the seas are cleaned?

(3) Would you like to become little researchers to come up with the solution?

(4) What can be done to raise awareness in our community about marine pollution?

(5) How can we use technology to arrive at a practical solution?

Junior search engine Safe Search (https://www.juniorsafesearch.com/)

Students are then asked to collect information on the topic at home from the computer, using the Junior Safe Search (https://www.juniorsafesearch.com/), from books, from discussions with their parents, and after recording them using multiple forms (painting, pictures, words, tables, etc.), they upload them to a padlet board prepared by the teacher https://padlet.com/dashboard. (see Figure 5)

**Figure 5** Digital quiz

## 3.3 $2^{\text{nd}}$ Phase: Science and theoretical concepts

We are organizing an online information meeting with Helmepa 's program manager Junior, who introduces the students to the program's mascot, the Seagull, who gives the students information about the seas and their importance, marine plastic pollution, microplastics, etc. and suggests activities to clean up our coasts and seas, but and helpful tips about our responsibilities to sea creatures and our planet. He then answers the children's questions by opening the doors of our school to scientists from the local and broader community.

## 3.4 $3^{\text{rd}}$ Phase: Design learning and engineering

Using https://www.canva.com/el_gr, the t oddlers design an infographic with images and data they receive from the https://helmepajunior.wordpress.com program. Charts are distributed to the students of all classes and their parents and relatives, contributing to their awareness.

## 3.5 $4^{\text{th}}$ Phase: Use of technology

Students assess their knowledge with the marine pollution quiz on wordwall (https://wordwall.net/play/15285/994/886). In addition, we create a diorama of the seabed just the way the kids want it through the app https://www.tinkercad.com/projects/How-to-Design-a-Digital-Diorama-Using-Tinkercad. Through simulation https://www.tinkercad.com/dashboard?type=circuits&collection=designs. After the teacher explains the circuit diagram to the students, they test the smart system that detects water pollution and discover how technology can be used to solve authentic problems of everyday life.

### 3.6 5$^{\text{th}}$ Phase: Educational robotics

With the help of a BeeBot robot and creating a robotic floor track from them, the students travel to the underwater world and design a story about the sea creatures' demonstration about the plastic and garbage that people throw at home, the sea.

### 3.7 6$^{\text{th}}$ Phase: Mathematics and replacing plastics in our lives

We make a table with plastic objects that we use in our daily life, and in an adjacent column, we mark a more environmentally friendly option (e.g., plastic bottle-thermos, plastic bag-canvas bag, plastic straw-paper straw, etc.), and then we create a poster with our correct behaviour towards the marine environment. We post it on the school blog, in prominent places in the yard, in the local press, and local shops after their owners' consent. We become little ambassadors and try to raise awareness as much as possible, while as a seal of the project, the voluntary cleaning of a nearby beach follows. (see Figure 6)

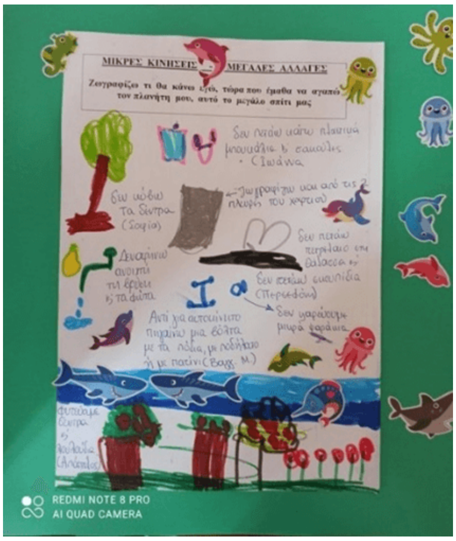


**Figure 6** Small moves, big changes.

## 4 Evaluation

Each group creates a presentation on canva.com to inform the rest of the students and teachers at the school about what they learned during the specific teaching scenario and encourage them to act according to the code of conduct they created (https://www.canva.com).

The groups' creations are presented to the students of the other departments and their teachers. In addition, the presentations are posted on the school's blog to raise awareness in the local and broader community.

In the plenary, the action is evaluated, and each student expresses the feelings that the project caused him. They draw what impressed them from the scenario, and everything together is captured on a padlet board (https://el.padlet.com/dashboard).

## 5 Discussion

Throughout the project, the toddlers showed enthusiasm for experimenting with the new tools and digital media and participated with undiminished interest and willingness in all stages of its development, devoting sufficient time outside the classroom and some of their free time. They were allowed to express themselves in many ways, collaborate, communicate, and acquire critical thinking and creativity skills through their participation in their group and the whole class. They were particularly excited about the engineering and technology part and were delighted with the results of their efforts. Their willingness to explore the planning process and actively engage in it without facing difficulties in the process was intense, which continued after the end of the educational intervention. They were informed in-depth, got to know new concepts, and positive results were on all the goals set, while at the same time, they developed programming, computational and algorithmic thinking skills. The scenario implementation was a different and impressive experience for the toddlers, who enthusiastically watched the project's development, taking an active role in discovering knowledge.

Active and experiential learning combined with dealing with and solving real problem situations activated the toddlers, who assumed roles and were allowed to function as active subjects, determining their learning development.

More specifically, the didactic intervention to engage preschool students in STEM through educational robotics with the programmable robot Bee-Bot showed that it is a didactic that easily fits in Kindergarten, given that teachers should be carriers of the knowledge of content and have acquired supportive learning skills for toddlers (Thulin & Redfors, 2017; Mamolo, 2022; Tallou, 2022; Xezonaki, 2022).

The teacher's design of authentic and integrated activities is easily achieved by utilizing STEM education, offering toddlers an environment full of challenges and questions to explore. In addition, using hands-on activities in conjunction with the floor-based programmable device produced only positive results and was a handy learning tool for the children, as they felt they could manage, program, and control the robot. In a second stage, toddlers who operated the Bee-Bot were introduced to programming commands and used command cards to help them program the Edison robot.

The project highlighted the impact of educational robots on the development of digital competencies of toddlers and that, ultimately, educational robots can effectively support STEM education in a kindergarten classroom and lead to new ways of learning. With the proper instructional intervention and taking advantage of kindergarten children's nature for inquiry, expression, discovery, and construction, educational robotics significantly contributes to their engagement with STEM education.

We strongly recommend using educational robotics in Kindergarten as an innovative learning environment and a practical educational tool. Well-designed and appropriate educational activities based on modern learning theories support students in developing knowledge, abilities, and skills, enhancing their teamwork, collaboration, critical and computational thinking, creativity, and engagement with STEM education.

# Conflicts of interest

The author declares that they have no conflict of interest.

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