ROBOAQUARIA: ROBOTS IN AQUATIC ENVIRONMENTS TO PROMOTE STEAM AND ENVIRONMENTAL AWARENESS

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Abstract

The paper explores the potential of robotics in environmental education, focusing on the ROBOAQUARIA project. It highlights the importance of integrating robotics into education - particularly within the field of Science, Technology, Engineering, Arts and Mathematics (STEAM), emphasizing creativity, critical thinking, and problem-solving skills. Research indicates positive outcomes across various disciplines within STEAM, including environmental education. Several projects demonstrate the effective use of robotics in teaching about environment. The ROBOAQUARIA project aims to integrate educational robotics into marine environmental education, offering a holistic approach involving equipment provision, teacher training, and curriculum development. Findings suggest potential benefits for schools.

Introduction

This paper examines the potential of robotics to assist in environmental education. The topic is explored through an innovative project called *ROBOAQUARIA: Robots in Aquatic Environments to Promote STEM and Environmental Awareness* which will run from 2022 until 2025. It includes a consortium of six organizations from five countries: Italy, Cyprus, Croatia, Ireland, and Greece. The program is funded by the European Union and belongs to the ErasmusPlus category.

Robotics in education, particularly within the field of Science, Technology, Engineering, Arts and Mathematics (STEAM), garners significant attention from educators, researchers, and policymakers. It seamlessly integrates into the interdisciplinary curriculum, emphasizing creativity, critical thinking, and problem-solving skills essential for future citizens. Educators must adopt innovative approaches to incorporate robotics effectively rather than relying solely on traditional curricula. Robotics activities require a wide range of real-world skills that require careful activity design by teachers. Research indicates that robotics education contributes to cognitive, affective, and psychomotor goals across various disciplines within STEAM, enhancing learning outcomes and promoting positive attitudes toward technology (Conde et al., 2021; Darmawansah et al., 2023; Kalaitzidou & Pachidis, 2023). Such a discipline can be environmental education (Christidi & Christopoulou, 2022; Kanaki & Kalogiannakis, 2023). It is important to ensure that any attempt to integrate robotics and environmental study into curricula should have long-term impacts on schools by improving students' performance and helping the schools run more efficiently (Fullan, 2007).

The project focuses on that topic. After a literature review about robotics in environmental education, it presents the project ROBOAQUARIA, which serves as the context of the study. Its importance, innovation, and contribution are explained. Then, in the methodology section, the data collection and analysis are presented, which leads to the conclusion and basic findings.

Literature Review

Robotics can be combined with environmental studies (Christidi & Christopoulou, 2022; Kanaki & Kalogiannakis, 2023). Before specifying the characteristics of this study, it is crucial to identify findings from previous research studies on this topic.

Robotics in Environmental Education

Talib et al. (2020) conducted a comprehensive investigation into the potential integration of robotics within educational frameworks to disseminate knowledge pertaining to sustainability and environmental concerns. By administering a questionnaire to participants drawn from two distinct university cohorts, the researchers sought to gauge perceptions regarding the utility of robotics in environmental education. The findings illuminated a consensus among respondents regarding the efficacy of robotics in fostering engagement with environmental topics, concepts, and phenomena. Furthermore, it was established that robotics can serve as a catalyst for the development of crucial STEAM competencies, which are instrumental in cultivating environmentally conscious attitudes.

Texeira et al. (2018) conducted a study that aimed at leveraging robotics as an educational tool to address the pressing environmental challenge of electronic waste management in Brazil. Recognizing the gravity of the issue and the imperative for proactive intervention, the researchers orchestrated a series of pedagogical interventions targeting high school students. These interventions encompassed the exploration of reusable product concepts and the environmental ramifications thereof. A pivotal aspect of the study involved the creation of a booklet elucidating the intricacies of electronic waste utilization, which was subsequently disseminated to a wider audience. Additionally, students engaged in the construction of a robotic kit which comprised reusable components, thereby acquiring practical knowledge in robotics and gaining insights into environmental stewardship through a hands-on experience.

Ziouzios et al. (2021) embarked on a project centered on cultivating environmental empathy among primary school students in Greece through the innovative integration of robotics. Central to their methodology was the design and deployment of a specialized robot equipped with audio-visual capabilities to convey narratives and information pertinent to climate change, pollution, and sustainability. Following exposure to the robot's educational narratives, students participated in problem-based learning activities aimed at fostering creative ideation and solution-oriented thinking regarding future environmental challenges. Notably, pre and post-intervention assessments facilitated the quantification of changes in students' levels of environmental empathy, with overwhelmingly positive outcomes indicating the efficacy of the robotics-enhanced educational approach.

Ruiz Vicente et al. (2020) embarked on an ambitious endeavor to instill a nuanced understanding of climate change among elementary school students in Spain through the implementation of a project intitled *Sustainable City*. This multifaceted initiative, spanning 14 instructional sessions, leveraged project-based learning methodologies to immerse students in various aspects of climate change mitigation and adaptation. Students were tasked with utilizing robotics kits to design, program, and deploy robots capable of addressing challenges related to sustainable mobility, biodiversity conservation, renewable energy utilization, and waste management. The data, which was collected via questionnaires, underscored the significant knowledge acquisition and motivation engendered by the robotics-centric educational interventions.

Collectively, these studies highlight the transformative potential of integrating robotics into environmental education paradigms. By providing learners with hands-on experiences and interactive learning opportunities, robotics-based pedagogies not only enhance understanding of environmental concepts but also foster the development of critical thinking skills and problem-solving abilities essential for addressing contemporary environmental challenges. Moreover, the interdisciplinary nature of robotics education, encompassing elements of Science, Technology, Engineering, Arts, and Mathematics, aligns seamlessly with the holistic objectives of environmental education. Through active engagement with robotics, students are empowered to become proactive agents of environmental change, equipped with the knowledge, skills, and attitudes necessary to navigate the complex interplay between technology and environmental sustainability (Ruiz Vicente et al., 2020; Texeira et al., 2018; Talib et al., 2020; Ziouzios et al., 2021).

ROBOAQUARIA: The Study Context

It is therefore justified that robotics and STEAM can be integrated into environmental education (Ruiz Vicente et al., 2020; Texeira et al., 2018; Talib et al., 2020; Ziouzios et al., 2021). However, this necessitates adequate preparation. Schools and educational institutions must be appropriately organized for this integration. This entails ensuring that teachers, curricula, and educational infrastructure are conducive to activities involving robotics, including those related to environmental themes. Teachers should possess familiarity with STEAM and relevant pedagogies, such as project-based learning, inquiry teaching, and problem-solving. This enables them to implement STEAM-oriented innovations effectively and achieve desired cognitive, affective, and psychomotor objectives (Conde et al., 2021; Darmawansah et al., 2023).

This study aligns with the aforementioned findings as it seeks to integrate robotics into the realm of marine studies. Specifically, it is situated within the ongoing ROBOAQUARIA project. The primary objective of this project is to utilize educational robotics as an innovative tool to merge STEAM and marine environmental education. To accomplish this, the project engages various stakeholders, including teachers, learners, and education managers, to develop the requisite capacities and competencies for interdisciplinary teaching concerning digital transformation toward sustainable development. The project comprises five distinct components or work packages. The first involves fund management and oversight. The second entails the development of a methodological framework for pilot studies, complete with guidelines for teachers and schools. The third component focuses on the preparation of toolkits and lesson topics, consisting of aquatic robotic fish and accompanying educational materials, such as syllabi and activities. The fourth component encompasses the development of an electronic learning kit and lesson plans. Finally, the fifth component involves communication, dissemination, exploitation, and policy recommendations in collaboration with school partners and associated entities.

The ROBOAQUARIA project's innovation and significance are underscored by several factors. Firstly, it explores the potential of STEAM and robotics in understanding marine ecosystems. Secondly, it operates across multiple European countries, each with its own national education context, and involves diverse organizations specializing in education and information and communication technologies (ICT). Thirdly, it adopts a holistic teaching approach that integrates technological equipment, including kits, software, and hardware, with educational tools, such as lesson plans, syllabi, and activities. Fourthly, the project aims not only to generate research output and findings but also to deliver instructional materials and packages for future use by teachers. Moreover, the project takes into account existing research findings, which inform and guide its activities. Teaching interventions within the project will emphasize active learner participation through project-based learning lesson plans and activities. These activities will include scientific discourse on marine challenges and programming of marine robotic kits, fostering teamwork, problem-solving, and evaluation. The learning outcomes will encompass both environmental subjects and robotics, with a focus on imparting knowledge, skills, and attitudes regarding the use of robotics in marine environmental studies. By adhering to these principles, the program is expected to be both innovative and effective (Fullan, 2007; Ruiz Vicente et al., 2020; Texeira et al., 2018; Talib et al., 2020; Ziouzios et al., 2021).

Methodology

This study examines the potential of schools to use robotics activities for teaching about marine environments. This will be explored by precisely defining the potential of the ROBOAQUARIA project to be implemented in schools and educational organizations effectively. In other words, it examines the potential of schools to successfully accommodate the innovation of this project. It is important to clarify research questions, data collection methods, and analysis steps (Cohen et al, 2017).

The Research Questions

The research questions focused on identifying whether any relevant project or intervention meet the criteria of effective teaching in both fields of robotics and environmental studies. What topics should the former, effective teaching in robotics, cover around Science, Engineering, and Technology, which are component fields of STEAM? It should also deliver skills of creativity, motivation, and problem-solving. Lastly, it should deliver interest, satisfaction, motivation, and attitudes that are complementary to robotics and technology generally (Conde et al, 2021; Darmawansah et al., 2023).

In what areas should the latter, effective teaching in environmental subjects, have common learning outcomes? Learners should gain knowledge about the environment, such as marine ecosystems, their structure, significance, and challenges. They should also develop skills, such as observation, collaboration, planning, and evaluating. Lastly, they should also develop positive attitudes, such as concern about the environment and interest in learning more about risks that threaten it and the possible solutions to those issues. There are certainly common points in the learning outcomes of STEAM and environmental education (Ruiz Vicente et al., 2020; Texeira et al., 2018; Talib et al., 2020; Ziouzios et al., 2021). Bearing in mind the above, the research questions of the study are:

1. Can STEAM bring about effective learning outcomes regarding marine environments?
2. Can such a teaching intervention have a long-lasting impact on the schools and their functions?

By answering these questions, it is possible to decide upon the feasibility of efficiently executing an innovative activity such as ROBOAQUARIA, leading to the improvement of school functions. The first research question, which concerns learning outcomes, refers to knowledge, skills, and attitudes that would be promoted. The second research question concerns the way pedagogies, infrastructure, teachers' competencies, and professional development are influenced and changed through the program (Conde et al., 2021; Darmawansah et al., 2023; Fullan, 2007; Kalaitzidou & Pachidis, 2023).

Data Collection and Analysis

The data for the study derives from reports submitted by each participant country at the end of every year that include information regarding the implementation and impact of the project. The formal procedure regarding the structure, content, and submission of these reports was determined in the application and initial plan of the ROBOAQUARIA project. Each report contains detailed information regarding the sample of the organization and the members who participated in the activities. The reports provide insights into the context of the organizations, their experience with STEAM, innovation, and the pedagogical practices that are usually implemented, and how they compare to the ones involved in the project. Moreover, the partners that completed the reports were expected to mention, among other data, whether there are detectable practices that can be adopted by the school and if there are available or accessible resources and manageable costs. Besides that, the reports provide a detailed description of how the implementation of activities took place, the learning outcomes, the benefits for the school, the advantages, and the possible risks.

A total of 25 organizations from all participating countries were included, including schools of different ages and levels, universities, research centers, and organizations, all of them involved in STEAM education.

The analysis was based on a qualitative approach. The answer to the first research question derived from data directly related to the implementation description and the learning outcomes. The answer to the second research question was derived from data regarding the impact on schools, resources, costs, and potential permanent adoption of the program's pedagogies and strategies. The data from the reports were coded, and two nodes were selected. The first one was *Learning Outcomes;* it addressed the first research question and contained nodes such as "knowledge", "skills", and "attitudes". The second one was *Impact;* it addressed the second research question and contained nodes such as "pedagogies", "infrastructure", and "teachers' competencies & professional development". These nodes were selected as according to Conde et al (2021), Darmawansah et al (2023), and Kalaitzidou & Pachidis (2023), they are the main topics related to STEAM and Robotics teaching. Each phrase, text, and part of the report was related to a specific code and node, depending on its content. Once the coding was completed, the nodes and codes were gathered and analyzed (Cohen et al., 2017).

Findings and Discussion

The results of coding, as presented in Table 1, show that all codes and nodes have been identified in the data.

The first research question concerns the areas in which the codes of the category *Learning Outcomes* were identified. Data from the reports supports the fact that implementation of the program can lead to significant learning outcomes. Some report comments could be classified under the code "knowledge", as they indicated possible cognitive outcomes. As mentioned in a participant report, knowledge gained from the project can be about digital technologies and robotics, because learners can better understand these concepts through the program. The knowledge can also be about Science through an interdisciplinary approach. These report comments, which are classified under the code "skills", referred to psychomotor outcomes such as competencies to carry out projects. Along with that, the importance of project-based learning and problem-solving approaches is frequently highlighted. There were report comments classified under the code "attitudes" that referred to affective outcomes, such as positive views, ideas, and motivation towards using technologies within environmental projects.

Table 1

Codes and Nodes (categories), Frequency, and Exemplary Quotes Identified in the Reports

Nodes & Codes	Frequency/entries	Report Comment Quotes
Node: Learning Outcomes	133	*"…. present a comprehensive view of the world of water, through clear and interesting displays, informed, helpful staff, and exciting live presentations"*
• **Code: Knowledge**	58 (43.6%)	*"Utilize technology, such as coding, robotics, and digital storytelling, to engage students in interdisciplinary activities"*
• **Code: Skills**	46 (34.6%)	"*Encouraging skills, such as creative and logical thinking, problem-solving, and collaboration is a workable practice….These skills are essential in a global context and can be integrated into curricula worldwide"*
• **Code: Attitudes**	29 (21.8%)	"*Teachers and students must be adept at utilizing digital tools for tasks, such as data gathering, analysis, and managing robotic systems*"
Node: Impact	74	*"by leveraging project-based learning as a central methodology for the school*"
• **Code: Pedagogies**	27 (36.5%)	*"The project seeks to promote education uptake by making learning more engaging and relevant*"
• **Code: Infrastructure**	22 (29.7%)	"*Funds: Budget for robotics components, tools, and technical support. Facilities: Lab space for robot development and testing"*
• **Code: Teacher competencies and professional development**	25 (33.8%)	"*The program will offer teachers guidance on robotics, engineering, and marine environment*' or '*Providing teacher training, including lesson plan implementations, Learning, Teaching, and Training Activities (LTTA), e-learning toolkits, and guidelines for educators.*"

Addressing the concerns of the second research question, there were various codes related to the category *Impact*. The code "pedagogies" was used to classify report comments in which the new approach is described as important, not only for the project but for the entire learning organization. Emphasis is given to pedagogies that relate to ethical and legal considerations, which are included in activities. The code "infrastructure" was used to classify report comments that relate to the schools' infrastructure, that is, the existence and use of tools, such as robotic kits and programming software. Finally, the code "teacher competencies" was used to describe report comments that imply that teachers will develop competencies and build knowledge from the program.

These report comments show that the program, which engages STEAM in teaching about marine ecosystems, is considered efficient. They also demonstrates that educational contexts are generally able to implement such relevant projects. The project is indeed an opportunity for the construction of new knowledge in Science, Robotics, and how technologies can assist in dealing with environmental challenges. There is a common belief that the most suitable approach for the project is through project-based teaching with hands-on activities. This can help learners actively engage and develop competencies, skills, and attitudes that will help learners deepen their understanding of the new knowledge and increase their motivation to study it further. This can enhance the possibility of relevant innovation to succeed (Conde et al., 2021; Darmawansah et al., 2023; Kalaitzidou & Pachidis, 2023).

The impact of the program on the school seems to be understood as significant too. The benefits for the school community are likely to go beyond the implementation of the program. As the participants pointed out in their reports, there is an emphasis on the enrichment of the school equipment. The schools will obtain equipment that can be used by educators in activities that can help learners further understand how robotics and modern technology can be used in favor of the marine environment, assist in their studies, and deal with relevant challenges. Apart from that, the provision for the professional development of teachers and members of the school community is also apparent and significant. This professional development focuses on technical matters, such as learning about robotics and equipment that can help with studying marine environments. It also focuses on pedagogical matters, such as analyzing lesson plans, syllabi, and curricula in which the equipment can be used. Project-based activities are frequently mentioned and are noted as appropriate and necessary for teachers to become more confident, which is highly possible thanks to the program. In short, teachers will become familiar with using the relevant technologies and will implement effective educational activities as part of their work. Thanks to these points, the program can generally induce a shift in the schools (Conde et al., 2021; Darmawansah et al., 2023; Fullan, 2007 Kalaitzidou & Pachidis, 2023).

Conclusions

The main finding of this study is that STEAM and Robotics can be used to teach about marine environments. This is justified by the reports of the project ROBOAQUARIA, which is innovative because of its mission and structure, as it includes participants from different countries. The teachers and the rest of the education industry express positive attitudes, comments, and ideas towards such innovations. Their advantages are significant. Firstly, they can lead to learning outcomes, as the students can gain knowledge, develop skills, and adopt friendly attitudes. These can be used to address the marine environment's ecosystems, conditions, and characteristics. They can also be used to address STEAM, robotics, design, and programming. The integration of the two fields can help students better understand how technologies can be used to aid understanding of marine environments and take better action towards their support and preservation. These findings are compatible with those of other projects that integrated STEAM and environmental study (Ruiz Vicente et al., 2020; Texeira et al., 2018; Talib et al., 2020; Ziouzios et al., 2021).

Secondly, the participants expressed that the project had a greater positive impact on the school community. The main reason is its holistic approach, which combines the provision of equipment, instructions, lesson plans, syllabus, curriculum, teacher training, and guidance. Thanks to this, the teachers and the school can become more familiar with project-based activities, cooperation, and innovation. These are competencies that the teachers believe they can gain from the project and described as crucial and useful for their work. This is also verified by literature as important (Conde et al., 2021; Darmawansah et al., 2023; Fullan, 2007).

In short, teachers and schools are willing to implement activities that combine robotics teaching in the context of marine environments and they support its necessity. Nevertheless, it is important to note that this study is derived from a single project. Before generalizing this conclusion, such a limitation should be taken into consideration (Cohen et al., 2017).

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