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Exploring the Use of Educational Robotics in Non-formal Learning Environments: A Systematic Mapping

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Abstract. *This paper presents a systematic mapping study on the application of educational robotics in non-formal educational settings such as science clubs, museums, libraries, extracurricular activities, and non-governmental organizations (NGOs). The aim of this study is to explore the potential and challenges of educational robotics in these settings, specifically in relation to teaching and learning in Science, Technology, Engineering, Arts, and Mathematics (STEAM) domains. A methodological approach was employed, involving the selection of papers based on specific inclusion and exclusion criteria. Our findings indicate that educational robotics not only fosters computational thinking, problem-solving, creativity, and collaborative skills but also enhances student motivation and self-efficacy. Furthermore, we identify various challenges associated with the implementation of educational robotics in non-formal settings. These insights may serve as a foundation for future research and pedagogical practices in the field.*

1. Introduction

Educational robotics is an interdisciplinary and multifaceted field that bridges the gap between physical and digital learning while offering interactive and hands-on activities. This concept has been defined and explored by numerous scholars, each providing their unique perspective and contribution to understanding the discipline.

[Papert 1980] one of the pioneers in this field emphasized the role of robotics as active learning tools, helping students in the process of designing and constructing their own robotic devices.[Martin 1996] further developed this concept by highlighting the constructivist and constructionist nature of learning in educational robotics, where hands-on experiences play a pivotal role.

The idea of "digital manipulators" introduced by [Resnick et al. 1998] opens new pathways for learning, where the amalgamation of physical and digital materials allows for enhanced learning and design experiences. This vision is expanded by [Chambers and Carbonaro 2003] and [Alimisis 2013] who view educational robotics as a compilation of instructional resources, pedagogical philosophies, and physical materials, making it a broad and comprehensive term.

[Petre and Price 2004], [Nourbakhsh et al. 2005], and [Williams et al. 2007] have underscored, respectively, the role of robotics in fostering motivation, autonomous robotic design, and experiential learning, thus turning the learning process into a complex, engaging, and problem-solving task in a real-world context.

With a focus on the integration of different fields and the application of knowledge in real-world scenarios, [Hussain et al. 2006] see educational robotics as an avenue to foster a deeper understanding of STEM subjects and improve problem solving skills. This perspective is echoed by [Barker and Ansorge 2007], [Nugent et al. 2009], [Liu et al. 2010], [Kazimoglu et al. 2012], and [Benitti 2012] who emphasize the utility of robots for education purposes, particularly to promote STEM subjects and stimulate the development of transversal skills.

[Bers 2008] and [Barker and Ansorge 2007] highlight the multidisciplinary aspect of educational robotics and how it provides a dynamic and interactive learning environment, encouraging learning by creating and customizing robotic devices. It is through this playful and innovative context that students improve their problem solving and teamwork skills [Liu et al. 2010], as well as their creativity, technological literacy [Alimisis 2013], logical thinking, and collaboration [Scaradozzi et al. 2015].

Educational robotics is also seen as a catalyst for mathematical problem-solving in early years education [Highfield 2010], a tool to enhance student satisfaction and self-efficacy [Liu et al. 2010], and an approach designed around teaching principles and learning outcomes [Riedo et al. 2012]. Notably, [Toh et al. 2016] and [Eguchi 2016] underscore its role in promoting cognitive, affective and psychomotor development, and 21st-century skills, including creativity, critical thinking, collaboration, and communication. Reinforces [Viegas D'Abreu and Villalba Condori 2017], educational robotics is a learning environment, in which the concrete and the abstract are reconciled, thus being able to solve tasks whose solution may require knowledge of different scientific areas.

Drawing upon the various definitions and concepts presented, we can synthesize the following definition for educational robotics:

Educational robotics is an interdisciplinary approach to learning that uses robots as pedagogical tools to promote a variety of skills and competencies in students. It encompasses the design, construction, and programming of robots, allowing students to participate in hands-on and interactive experiences that facilitate learning in areas such as Science, Technology, Engineering, Arts, and Mathematics (STEAM). This approach fosters computational thinking, problem solving, creativity, and collaboration skills, which are essential for the 21st century. Moreover, educational robotics has the potential to boost students' motivation to learn, improve their attitudes toward school, and enhance student self-efficacy.

Non-formal education, as described by the International Standard Classification of Education (ISCED 2011), [UNESCO 2012], is a system that operates alongside and complements formal education, characterized by institutionalization, intent, and planning of an education provider. It distinguishes itself through its role as an addition, alternative, or complement to formal education in individuals' lifelong learning processes, often aiming to ensure universal access to education. Unlike formal education, non-formal education does not necessarily follow a continuous pathway, and it can take different forms such as short courses, workshops, or seminars.

This form of education covers a wide range of programs, including adult and youth literacy, education for out-of-school children, life skills, work skills, and social or cultural development. It might also involve job training to enhance or adapt existing qualifications and skills, or provide alternative educational pathways to formal education in some cases. Although the successful completion of non-formal education programs doesn't usually grant access to higher levels of education without validation in the formal system, it plays a significant role in the global education landscape, offering alternative routes for learning and skill development [UNESCO 2012].

The objective of this study is to conduct a systematic mapping of the application of educational robotics in non-formal educational environments. Through this systematic mapping, we aim to explore the potential and challenges that educational robotics present in these settings, specifically focusing on STEM learning domains. This paper employs a rigorous methodological approach, involving a review of selected papers based on specific inclusion and exclusion criteria.

The relevance of this study resides in the possibility of serving as a basis for future research and teaching practices. The aim is to fill the gap in the existing literature by examining the specific role and impact of educational robotics in non-formal educational settings.

2. Methodology

In conducting this systematic mapping study, we adhered to the methodological guidelines defined by [Kitchenham et al. 2007] for performing systematic literature mapping in the field of software engineering (Kitchenham, 2007). These guidelines advocate for rigor, transparency, and reproducibility in the systematic mapping process. This section further details the specific methodological strategy customized to meet the unique requirements and context of this study, especially the application of the Population, Intervention, Comparison, Outcome and Context (PICOC) criteria, as recommended by Kitchenham.

The Population (P) of our study constitutes students of various age groups participating in non-formal education programs, especially those associated with non-governmental organizations (NGOs). This population represents the target group impacted by the intervention of interest.

The Intervention (I) for this research is the implementation of educational robotics as a teaching and learning tool. We aim to examine its usage and implications in non-formal educational settings, understanding its potential and effectiveness in such environments.

The Comparison (C) refers to traditional teaching methods currently being employed in non-formal education settings, without the use of educational robotics. This comparison allows us to determine the potential benefits and improvements resulting from the intervention of educational robotics in these contexts.

The Outcomes (O) we seek to investigate are the changes in students' STEM learning outcomes, the development of 21st-century skills (including critical thinking, problem-solving, creativity, collaboration), and shifts in attitudes towards STEM subjects following the implementation of educational robotics.

Lastly, the Context (C) for our study comprises non-formal education settings such as community learning centers, clubs, after-school programs, NGOs, and similar environments. These settings provide the real world context in which the intervention of educational robotics is applied and its outcomes are observed.

By applying the PICOC criteria, we can establish clear and specific research questions and ensure a systematic approach to select and analyze the relevant literature. These criteria will further assist in refining the search strategy and identifying studies that offer meaningful insights into the field of educational robotics within non-formal education settings.

The online tool, Parsifal, served as the main platform for organizing and conducting this research. Parsifal was designed in accordance with the guidelines set forth by Kitchenham et al. [Kitchenham et al. 2007] for systematic review and mapping. This collaborative tool facilitates efficient cooperation among researchers dispersed geographically.

2.1. Research Questions

Based on the objective of SLM and using the PICOC strategy (population, intervention, comparison, outcome, and context), as recommended by [Kitchenham et al. 2007] and employed in the Parsifal tool, the following research questions were delineated. The following section provides an overview of these research questions.

- How is educational robotics being used in non-formal education environments?
- What are the reported outcomes of using educational robotics in non-formal education?
- How does the use of educational robotics in non-formal education affect students' engagement and motivation?
- What are the future prospects and recommendations provided by existing literature on using educational robotics in non-formal education?

2.2. Inclusion and Exclusion Criteria

To streamline the article selection process, we have defined clear inclusion and exclusion criteria for the study.

Inclusion criteria include the following:

- IC1 - Studies that involve the use of educational robotics in non-formal education settings;
- IC2 - Research that presents data on learning outcomes, skill development, engagement, or motivation related to the use of educational robotics in non-formal education;
- IC3 - Studies that involve learners identified in the population category of the PICOC (students, learners, youth, children, adolescents);
- IC4 - Studies published in English;
- IC5 - Empirical studies (qualitative, quantitative, or mixed-methods).

Exclusion criteria include the following:

- EC1 - Duplicated studies;
- EC2 - Secondary and tertiary studies;
- EC3 - Studies that do not present data related to learning outcomes, skill development, engagement, or motivation, or do not involve the learner populations identified in the PICOC;
- EC4 - Studies not published in English;
- EC5 - Non-empirical studies such as opinion pieces, editorials, or personal reflections;
- EC6 - Studies published before the year 2013;

2.3. Search Strategy and Databases

According to [Kitchenham et al. 2007], the selection of suitable keywords should align with the search question in hand. In this study, the online tool Parsifal was used to facilitate the inclusion of keywords and the corresponding synonyms. This tool generated a search string by concatenating keywords and their synonyms using the logical operator OR. Subsequently, all keywords were associated with the logical operator AND. The search string resulting is presented in Table 1.

Table 1. PARSIFAL String

("adolescent" OR "teenagers" OR "children" OR "child" OR "kid") AND ("skill" OR "skills" OR "kit" OR "kits" OR "teaching and learning approach" OR "teaching and learning methods" OR "simulators") AND ("educational robotics" OR "pedagogical robotics") AND ("non formal education" OR "NGO" OR "non-governmental organization")

This string, Table 1, ensures that the retrieved studies correspond closely to the PICOC criteria and the research questions. It is worth noting that for each database the string had to be calibrated. Following the retrieval of the studies, they will be subjected to the inclusion and exclusion criteria for the final selection. The following sections will detail the process for data extraction and synthesis.

The literature search will be conducted across multiple databases to ensure a comprehensive review of relevant research.

3. Conducting the SML

In the process of conducting a systematic literature review, various databases were utilized for the purpose of sourcing relevant studies on the topic of educational robotics in non-formal education environments.

These databases included the ACM Digital Library, IEEE Digital Library, ScienceDirect, Scopus, and Springer Link. The number of articles retrieved from each database varied significantly, indicating a disparity in the prevalence of research on the topic between different sources.

A total of 13 articles were recovered from the ACM Digital Library, while the IEEE Digital Library and Springer Link did not produce any relevant articles. From ScienceDirect, 7 articles were found and only 1 article was in SBC OpenLib (SOL). However, the Scopus database proved to be the most papers, producing a total of 35 articles. The

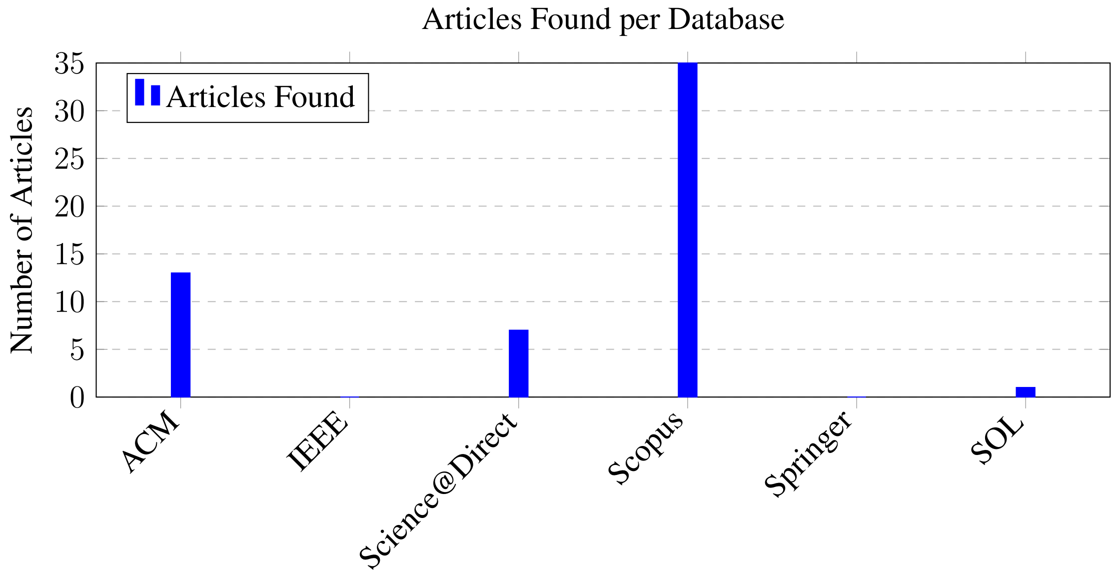

Figure 1. Number of articles per Database

differences in the distribution of articles between databases are visually represented in Figure 1.

4. Results

In applying the exclusion criteria, several articles were omitted from our study. Specifically, 2 were duplicates, 3 were not published in English, 36 did not involve educational robotics or non-formal education settings, 2 did not present data related to learning outcomes or identified learner populations, and 4 were classified as tertiary literature. However, the application of our inclusion criteria resulted in the inclusion of 8 studies.

A unique ID was assigned to each article for ease of cross-referencing throughout this study. This unique ID, along with the title, author(s) and publication year of each article, is presented in Table 2. This provides a preliminary understanding of each article's content and context.

The chosen articles span multiple academic journals, reflecting the interdisciplinary nature of the field of educational robotics. The journals encompass fields ranging from engineering to social and behavioral sciences, reinforcing the broad applicability of educational robotics. This breadth underscores the importance of educational robotics across various contexts including technology-enhanced learning, computing education, and the integration of coding and robotics in education, including potential applications in non-formal education settings.

Our mapping also revealed the most frequently occurring keywords among the articles: “education,” “robotics,” “non-formal education,” “computational thinking,” “coding,” and “educational robotics”. However, it should be noted that this keyword analysis is limited by the specific scope and sample of this study.

Table 2. Articles selected for the literature mapping

ID	Article	Author/Year
1	Resources and Features of Robotics Learning Environments (RLEs) in Spain and Latin America	[Pittí et al. 2013]
2	Learning Activities Suitable for an ICT-oriented Children's Summer Camp	[Cápay et al. 2015]
3	Activity plan template: A mediating tool for supporting learning design with robotics	[Yiannoutsou et al. 2017]
4	Coding skills as a success factor for a society	[Tuomi et al. 2018]
5	Online learning facilities to support coding and robotics courses for youth	[Demertzi et al. 2018]
6	Learning environment for robotics education and industry-academia collaboration	[Lanz et al. 2019]
7	Implementing a computational thinking curriculum with robotic coding activities through non-formal learning	[Lee and Low 2020]
8	Finding fun in non-formal technology education	[Pienimäki et al. 2021]

5. Discussions

In this section aims to delve into the core questions posited in Section 2.1 through an analytical discussion that integrates the findings from our systematic literature review. This section serves as a critical synthesis of the research landscape, addressing each research question in the context of existing work. We will explore the methodologies employed, target audiences, challenges faced, and results presented in the studies examined.

5.1. How is educational robotics being used in non-formal education environments?

Educational robotics, as substantiated by studies conducted across Spain and Latin America, has found application in non-formal education environments [Pittí et al. 2013]. The investigation focused on the usage of Robotics Learning Environments (RLE) within traditional classrooms and after-school programs, giving special attention to the teacher's profiles, technological resources employed, and the unique attributes of RLEs.

In more informal setups, such as children's summer camps, [Cápay et al. 2015] proposed five learning activities including educational robotics. The robotics-related activity employed LegoMindstorm kits, where the children engaged in three tasks: building a car, programming using NXT blocks, and participating in a competition.

Suggesting a more versatile approach, [Yiannoutsou et al. 2017] proposed the development of a generic activity plan template. This template can be used in various learning environments irrespective of the type of robotic kit deployed, thus supporting diverse stakeholders in designing learning activities.

The study by [Tuomi et al. 2018], while predominantly focused on programming, also underscores the possibility of learning and practicing coding skills beyond formal education. This is facilitated by the engagement of various groups including after-school clubs, non-profit organizations, commercial entities, and FabLabs following the makers' culture.

In an example of leveraging vacation periods, [Demertzi et al. 2018] present the European project Code@Youth. This project introduces students to programming and robotics through a mix of online and hybrid learning activities during the summer break.

[Lanz et al. 2019] proposed a learning environment, Tampere RoboLab, that targets both formal and non-formal education to teach robotics. The study by [Lee and Low 2020] utilized a robotic ball to teach computational thinking in extracurricular activities spanning six weeks. Lastly, [Pienimäki et al. 2021] analyzed how enjoyment in non-formal technology education is derived by 8-17-year-old children in Finland. The authors identified three main fun aspects: the enjoyment derived from task completion, social enjoyment from interaction with other participants, and pedagogical enjoyment embedded in the learning process.

5.2. What are the reported outcomes of using educational robotics in non-formal education?

In their study, [Pittí et al. 2013] underscore the importance of equipping teachers with the necessary training to effectively use educational robotics. The balance of didactic and technical aspects is crucial in creating a meaningful learning environment through robotics, applicable in both regular school sessions and after-school programs. The design of Robotics Learning Environments (RLE) should take into account the harmony amongst various elements such as context, technology, and pedagogy.

Reflecting on their activities, [Cápay et al. 2015] reported that the feedback from the participants, children aged 8-14 years, parents, and volunteers, was overwhelmingly positive. In particular, they found age-dependent preferences in educational robotics activities, with younger children gravitating toward play with legos, while older children showed interest in learning new block programming commands. In their approach to coding education, [Tuomi et al. 2018] presented six examples, two of which involved non-profit initiatives, Innokas and Koodioulu, integrating robotics into their activities.

[Demertzi et al. 2018] provided students with opportunities to learn how to program an Edison robot through a graphical interface. The feedback received from students was positive, appreciating the value of their summer break being used constructively to acquire digital skills and learn concepts typically beyond the scope of traditional school curricula. The unique program set itself apart from conventional school lessons by fostering active learning through engaging exercises and activities.

[Lanz et al. 2019] underscored two potential outcomes of their proposed learning environment, focusing on educational and social perspectives. From an educational standpoint, the environment aimed to streamline the learning process, accommodating diverse robotics projects to bridge the gap between theoretical learning and practical industry applications. On the social front, the authors advocated for increased accessibility and visibility of the environment, democratizing access to educational robotics, and ensuring user safety.

A study by [Lee and Low 2020] showed a positive reception for their activities, with 98% of the 38 participants providing favorable feedback. Lastly, [Pienimäki et al. 2021] postulated that pedagogical fun could have increased importance in relatively formal activities that adhere to a clear curriculum. This approach ensures the participation of participants even in activities that they may not initially show interest in.

5.3. How does the use of educational robotics in non-formal education affect students' engagement and motivation?

In their conclusion, [Pittí et al. 2013] propose that educational robotics can cultivate a meaningful learning environment, either within regular classrooms or after-school programs, provided there is a balanced approach to designing Robotics Learning Environments (RLEs). This balance, considering elements like context, technology, and pedagogy, can amplify student engagement and motivation, aligning with the demands of 21st-century skills.

According to [Cápay et al. 2015], students should actively build their own knowledge through experiential activities and personal involvement. Such experiences can potentially stimulate further learning and facilitate effective assimilation of new knowledge.

Within the Tools category featured in the "Criteria used for the selection of best practices" table, it can be discerned that [Yiannoutsou et al. 2017] suggest the engagement of participants could be amplified by making the resulting artifacts intriguing and appealing. Subsequently, these artifacts could find applicability in various domains of participants' lives.

[Tuomi et al. 2018] emphasize that several studies have demonstrated how educational robotics activities foster an enjoyable learning process, increasing student motivation, collaboration, self-confidence, and creativity. Furthermore, they assert that the maker culture can be incorporated into schools to support and actively involve students in learning science, technology, engineering and mathematics (STEM).

Based on their findings, [Demertzi et al. 2018] report that students showed genuine enthusiasm to continue these hybrid coding and robotics learning activities and expressed anticipation for future training sessions that cover a wider range of topics.

The matter at hand is not discussed in the articles by [Lanz et al. 2019] and [Lee and Low 2020]. Finally, [Pienimäki et al. 2021] note that younger children appear to derive enjoyment from hands-on tasks, such as experimenting with their projects (e.g., operating LEGO Mindstorms robots). On the contrary, older children seem to derive satisfaction from overcoming challenges and achieving success.

5.4. What are the future prospects and recommendations provided by existing literature on the use of educational robotics in non-formal education?

[Pittí et al. 2013] propose future research directions that involve an exploration of students' perspectives on these educational tools, in addition to an investigation of the relationships between the characteristics of Robotic Learning Environments (RLEs), teaching methodologies, and learning outcomes.

[Cápay et al. 2015] suggest future research efforts should focus on activities that combine elements of collaboration and creativity. They also recommend the inclusion of positive emotional experiences, real-world problem-solving tasks, and the use of modern technological tools in the learning process, striving to ensure that this incorporation is done seamlessly and meaningfully.

Although [Yiannoutsou et al. 2017], [Demertzi et al. 2018], [Lee and Low 2020] and [Pienimäki et al. 2021] do not address this issue, it is worth mentioning that

[Pienimäki et al. 2021] presents three forms of fun, which contribute to the overall positive experience of the non-formal technological education and play a significant role in motivating and engaging children in educational activities. [Demertzi et al. 2018] reinforces the growing urgency of educating the next generation in the areas of computer science, ICT and digital literacy, the authors also reinforce that students need to have the necessary knowledge and skills to use technological tools and achieve digital literacy , thus enabling them to effectively navigate the ever-evolving digital landscape.

[Tuomi et al. 2018] assert the need for global research aimed at gathering data on various strategies, with the objective of developing a more extensive framework for current Information and Communications Technology (ICT) skills, coding skills, logical thinking abilities, and programming competence.

Regarding the Tampere RoboLab environment, which follows the FabLab principles, [Lanz et al. 2019] indicates plans to expand services and co-creation activities. This expansion aims to enhance the collaboration between industry and academia and facilitate lifelong learning in various industrial sectors. Works not mentioned in this subsection do not address the topic of future prospects and recommendations in the use of educational robotics in non-formal education settings.

6. Conclusion

This systematic mapping study offered an exploration of the application of educational robotics in non-formal education settings, highlighting its potential to improve teaching and learning outcomes, and highlighting some challenges that need to be addressed for more effective implementation.

Integrating educational robotics into non-formal education has the potential to offer a number of benefits, including promoting 21st century skills, increasing student motivation, promoting collaboration, creativity and self-confidence, and providing meaningful learning experiences. However, for these benefits to be achieved, existing challenges such as teacher training, technology inconsistencies, and the need for balanced RLE design must be proactively addressed.

As we look forward, it is also pertinent to consider the contrasts and similarities between the adoption of educational robotics in formal and non-formal settings. More research is needed to expand on these findings and recommendations. The future of educational robotics in non-formal education environments looks promising, and with ongoing research and technological advances, a continued evolution of this field is expected. This topic offers a rich avenue for future research.

Furthermore, future research can explore students' perspectives on these tools and the relationships between RLE resources, teaching methodologies, and learning outcomes, increasing participant engagement. This will provide more detailed information on how best to integrate robotics into non-formal learning environments and enhance the teaching and learning process.

We can say that educational robotics presents an excellent opportunity to enrich non-formal education and equip students with the necessary skills to thrive in the 21st century. However, it also requires careful planning, strategic implementation, and continual evaluation to ensure its benefits are realized.

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