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Systematic review: Potential effectiveness of educational robotics for 21st century skills development in young learners

Saira Bano[1] · **Kanwal Atif**[1] · **Syed Atif Mehdi**[1]

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Abstract

Educational Robotics (ER) is an upcoming trend in education. It has been introduced in classrooms to improve the learning environment. It provides opportunities for young learners by promoting knowledge-building activities. STEM (Science, Technology, Engineering, and Mathematics) education is viewed as a catalyst to ensure a successful future in the context of real-world issues. ER is an innovative tool that can provide a roadmap for quality education. This study aims to investigate "What skill-set does ER (Educational Robotics) develop in young learners?", "How does robotics intervention affect young learners?", and "Whether Educational Robotics (ER) facilitates STEM education?". We systematically reviewed the literature on robotics and the importance of STEM, identifying the role of robotics in both formal and informal elementary and secondary classrooms, after-school programs, and summer camp activities. We used the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) methodology to analyze 20 relevant articles. We searched articles by using keywords and the snowballing technique. The study of recent applications of ER suggests that it aids in a precise and flexible understanding of STEM concepts.

Keywords Educational robotics (ER) · STEM education · Learning skills · Robots · School education

✉ Saira Bano
L1S21MSCS0003@ucp.edu.pk

[1] Center of Robotics, Faculty of Information Technology and Computer Science, University of Central Punjab, Lahore, Pakistan

1 Introduction

STEM (Science, Technology, Engineering, and Mathematics) is a broad field with numerous educational disciplines, activities, and resources. Its primary aim is to prepare students for future challenges and motivate them to pursue a career in this multidisciplinary field and develop hands-on experimental, critical thinking, and problem-solving skills (Dochshanov & Lapina, 2019). Educational Robotics (ER) occurred, established, and continues to grow at the cross-section of educational sciences and computational science, contributing to both didactic scientific areas. The theory of constructionism (Papert, 1980) guides the implementation of ER activities. It aids in the development of computational thinking skills, collaborative learning, and project-based learning by including student-robot interaction (Sáez López et al., 2021). ER is an innovative tool that uses robots for learning in a broad range of educational environments. It is a powerful and effective field that provides a unique approach to promoting STEM education (Jung & Won, 2018).

1.1 Educational robotics in STEM education

Through robots, ER explores uncharted territory in STEM to improve understanding in young learners by piquing their interests and assisting in the implementation of current ideas and the creation of innovative ideas. This method can assist in making this learning activity more interesting and enjoyable (Khine, 2017). ER is a pedagogical approach that helps young learners develop skills and improves their understanding of this interdisciplinary field (Amo et al., 2021). However, introducing robots at the school level is a challenging task. At this age, it is necessary to define a technique to make learning fun. Several age-appropriate robotic kits based on children's interests are available for this purpose and can be used in primary and secondary schools to develop computational thinking, problem-solving, and analytical skills (Papadakis, 2020). As a result, incorporating ER into an educational setting is a one-stop shop for learning the areas of science, technology, engineering, and mathematics (Hudson et al., 2020). Learning with robots can assist in visualizing real-world challenges for a variety of problems and helps learners in transitioning from theoretical to practical experience (Zhong & Xia, 2020).

In both formal and informal educational content, ER is eminent as a power to educate learners for future needs. It aids in increasing students' motivation to learn. Most STEM activities are a minor component of formal education for school-age students because they necessitate education that allows them to revisit previous events and experiences to create something new or modify existing things (Sáez López et al., 2021). Robotics motivates students to learn independently and has no negative impact on self-efficiency. It also helps to understand the complexity of this difficult multidisciplinary field and define that it required teamwork (Tsoy et al., 2018). Robotics helps in teaching and learning processes by allowing young learners to gain practical experience while accepting and embracing changes brought about by complex environments and applying knowledge in real-world situations (Jung & Won, 2018).

1.2 Significance of educational robotics

Many conferences, especially those in the academic community, have emphasized the importance of ER in education. However, the main challenge is motivating students to learn technology. For this, several robotic-based kits are available to aid in the gradual integration of STEM concepts into curricula (Amo et al., 2021). In recent years, teenagers have been drawn to robot competitions to spark their interest in technology. Different platforms for plug-and-play modules, such as Arduino, LEGO Mindstorms, and Raspberry Pi are available to help students quickly develop different prototypes and modules in ER (Dochshanov & Lapina, 2019).

Several commercial robots are also being used for educational platforms. The well-known LEGO has several versions, including Mindstorms RCX, NXT, EV3, and WeDo which includes software compatible with the Scratch programming language (Vega & Cañas, 2018). Several studies have been conducted to investigate the impact of ER on young learners' social and academic skills. Educational robots are used in various contexts to increase student interest, engagement, and academic achievement in interdisciplinary fields (Anwar et al., 2019). It is a branch of novel educational technologies, that is widely used and involves STEM support. This is based on the "learning by doing" model, which allows students to acquire knowledge through actions (Syriopoulou-delli & Gkiolnta, 2021). Hence, it is beneficial to emphasize this specific educational method to develop cognitive and learning skills. This calls for a modern learning environment that can be established using already-developed innovative tools and methods (Kubilinskiene et al., 2017).

1.3 Preparing young learners for 21st centaury

The rapid evolution of technology is a major driver of new opportunities in education. ER is regarded as a promising educational trend. Innovative tools and methods can be used to create a modern learning environment, and ER can provide these opportunities to students in an effective way. Many teachers and researchers believe that teaching robotics to children will help them improve their logical thinking, creativity, teamwork, ability to respect other people's ideas, and communication skills. Concepts from primary curricula in mathematics and science are less effective for problem-solving in robotics, engineering, and computer science (Scaradozzi et al., 2015). Papert's (1980) constructionism is an educational method based on an ideology that uses a student's knowledge and experience to help him more effectively. The basic idea is to learn using tools like robots, which allows children to actively construct their skills (Sáez López et al., 2021).

Many countries and regions have wanted to promote STEM education globally in recent decades, concluding that it is especially important for young learners (Zhong et al., 2022). Moreover, the demand for STEM-educated employees is increasing steadily. This requires a greater emphasis on preparing students for future needs and facing the challenges of the next generation making STEM education a critical step towards ensuring the world's future prosperity (Chou, 2018). As a result, there is an urgent need to prepare and strengthen students' scientific thinking, polish mathematical complex concepts for inquiry-based learning, and improve problem-solving skills (Kopcha et al., 2017). Children could not read when they are in kindergarten, thus the introduction of robots at an early age has a positive impact on increasing the learning time spans. Pepper robot; was an appropriate pick for this subject. Both teachers and educators have given excellent reviews (Schiffer & Ferrein, 2018). Robotics is gaining popularity among teachers, educators, and researchers since it provides an opportunity to strengthen these skills by combining technology and engineering. It also aids in the investigation of the educational design process to promote STEM concepts (Abidin et al., 2021). According to pragmatic evidence of teaching and learning through robotics, and investigations in future research perspectives on robot-assisted education, robotics is viewed as an effective tool for hands-on learning (Zhong & Xia, 2020).

1.4 Education through robotics

Both ER and its tools are effective for a wide range of subjects and applications for students of all ages (Kubilinskiene et al., 2017). Several platforms have been developed and used for educational purposes, for example, the spiderino robot is an autonomous robot built on a toy platform and provides an excellent opportunity to work on various technological dimensions such as programming robots, 3D printing, actuators, sensors, and swarm intelligence (Jdeed et al., 2020). Multiple studies have shown that ER is spreading globally to support STEM education because of its ability to realize engaged multidisciplinary activities in science, technology, engineering, mathematics, arts, language, and humanities. It also supports exclusive education in computer science and robotics for all ages. This study report presents a novel application of machine learning in the field of ER, identifies alternative problem-solving paths, and investigates how students learn to use sensors during ER activity (Scaradozzi et al., 2020). Various robot kits have been developed, for example, KIBO, Cubetto, COJI, Bee-BotBot, and Thymio. Tinkerbots and mTiny are available for use in Primary schools, increasing the learning environment, promoting knowledge-building activities, and providing opportunities to young learners (Papadakis, 2020).

1.5 Informal STEM education

Activities at summer camps can inspire and foster an interest in STEM. This effort was successful in engaging the underrepresented group, involving females' participation, and it produced fruitful outcomes. Parents are willing for this kind of activity in the future and inform others because they prefer hands-on learning experiences and excitement for their children, rather than a presenter's lecture in a traditional way (Mohr-Schroeder et al., 2014). Robotics training camps for educational purposes require several factors and issues to be considered, as well as key components and potential construction-related concerns. The environment has significant effects on participants' experiences during robotics training camps. Effective curriculum design is critical for the success of educational robotics training camps in terms of age-appropriate learning goals. The role of instructors and facilitators in such activities is particularly crucial, as is the size of the group because collaboration and teamwork are necessary for this hands-on activity. Summer camp activities emphasize the value of educational robotics training programs in advancing STEM education and developing children's enthusiasm and expertise in robotics. Educational robotics training camps have a lot of potential for promoting STEM education and developing future innovators (Ucgul & Cagiltay, 2014).

1.6 Robotics competitions as motivation

Robotics competitions and educational robots are becoming popular educational activities involving youngsters in collaborative critical thinking and problem-solving. Educational robots have shown positive effects in enhancing students' involvement and interest. Since creating the Logo programming language in 1967, ER has become a significant educational tool in K–12 STEM educational settings (Anwar et al., 2019). The First LEGO League (FLL) Challenge competitions have wide-ranging benefits beyond robotics. The students' perspectives on various areas of science, technology, engineering, and mathematics have been changed because of participating in these events. These short-term activities have a positive impact on students' attitudes, especially in females. (Graffin et al., 2022). Student teams design, build, and program robots to participate in various challenges, and these competitions provide an exciting and engaging approach for students to learn about robotics and STEM concepts (Kyprianou et al., 2023).

The importance of STEM education to equip young learners with essential technological skill-sets is evident from the past 10 year's research in this field. However, the introduction of ER in the K-12 curriculum, on the other hand, is still an emerging concept, which needs to be further investigated to evaluate its true significance.

This paper is divided into five sections. The second section describes the study's research methodology. The third section depicts the role of ER in enhancing various skills in young learners. The fourth section discusses the significance of ER in STEM education and its effects on learning outcomes. The conclusion is discussed in the last section.

2 Methodology and material

The study's main goal is to highlight the impact of STEM and ER on young learners based on existing literature. We used the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis); the systematic methodology to create a well-grounded literature review (Moher et al., 2009). This is a well-known protocol for conducting a systematic review. We established inclusive and exclusive criteria for gathering relevant studies. In terms of age group, our research focuses on elementary and secondary school levels. However, the number of international studies focused on elementary and secondary school was small in comparison. We chose journal and conference articles that look at ER in STEM as a learning tool and a discipline. We included both qualitative and quantitative studies in this review. For our research questions, we analyzed and selected relevant articles. To clear the way, we have defined three questions.

Question 1: What skill-set does Educational Robotics (ER) develop in young learners?
Question 2: How does robotics intervention affect young learners?
Question 3: Whether Educational Robotics (ER) facilitates STEM education?

Initially, we performed a snowballing approach to identify the existence of a systematic review involving robotics in school education. We applied snowballing on an initial paper (Benitti, 2012) on the subject as a base paper to include all the papers that have cited it. In the first round, we found 253 papers, and we selected 3 most relevant papers according to our inclusive criteria. After the second round, we found 76 papers and further selected 2 studies. As a result, 5 papers (Ucgul & Cagiltay, 2014), (Chou, 2018), (Karaahmetoğlu & Korkmaz, 2019), (Papadakis, 2020), and (Demir Kaçan & Kaçan, 2022) have been shortlisted for this study.

However, in order to ensure completeness and reproducibility, we also searched for scholarly articles in these four databases: Google Scholar, WoS (Web of Science), Scopus, and ProQuest; and looked at articles written in the English language between 2012 to 2022. The literature has evidence of existing studies on robotics at the elementary and secondary levels. The study by (Amo et al., 2021) focused on the learning of robotics sensors while (Zhong & Xia, 2020) focused on the effects of ER especially on mathematics education. (Graffin et al., 2022) studied the effects of a specific robotic competition on students' learning and STEM attitude. (Anwar et al., 2019) gives a nice review of the studies done on ER, however, the study is up to the year 2018. There is a need to examine the latest experimentation and studies being done in reference to the significance of ER in learning STEM skills in secondary and K-12 students. The search string used is "robot AND STEM AND (education OR school OR curriculum OR student) AND learning AND (primary OR elementary OR secondary OR K-12)".

Database search resulted in 288 articles from Google Scholar, 49 from WoS, 76 from Scopus, and 37 articles from ProQuest. Initially, we found 450 articles. In the second step, we removed 89 duplicate articles. Following that, we discovered 118 articles that did not have full-text availability. In the third step, we eliminated 57 articles that had nothing to do with our topic. Of the remaining articles, 171 were rejected for several reasons, such as the use of robots to assist with impairment problems or to supplement any other special needs. A few articles were incomplete, and some were written in other languages. There were a few studies about spatial robots, and some focused-on dance, music, and gaming, as well as an extended version of previously published studies, experimental studies of undergraduate students, and dissertations. Articles about teachers' training were also removed. Finally, we had 15 related studies that met all the

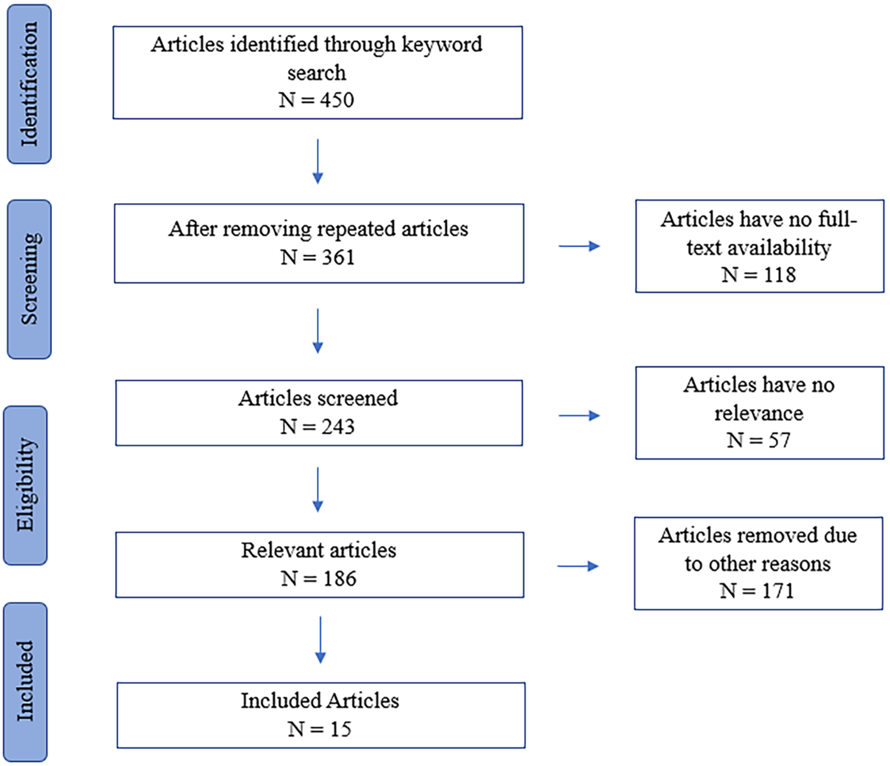

Fig. 1 Flow diagram to show the selection procedure

criteria as shown in Fig. 1. Therefore, in total 20 articles have been selected for this systematic review.

Search results have been analyzed and selected according to the following criteria.

2.1 Exclusive criteria

Articles focusing on K-12, pre-kindergarten and pre-school robotics, and pre-university robotics were excluded. Book chapters, as well as secondary or tertiary source articles were also left out.

2.2 Inclusive criteria

We included qualitative and quantitative studies, experimental studies, scenario-based learning, and project-based learning. Articles that present feedback data on learning outcomes, in addition to robots introduced to elementary and secondary school students were also included.

2.3 Selection process

We reviewed the abstracts of the publications after many screenings. However, due to the defined criteria, it would have been difficult to eliminate articles by trying to analyze abstracts. It was decided to look for more information in the remaining article's body. A few studies were unrelated to our broad criteria. Following that, we removed a few articles for distinct reasons. As a result of a thorough analysis, the articles that met the set criteria were chosen.

A time-based analysis of the selected papers shows that there is a single publication in 2012 and 2015, two articles in 2014, and two publications in 2016, respectively; four publications in 2018, 2019, and 2020, no publications in 2013, 2017, and 2021, and two papers in 2022. The publications per year are depicted in Fig. 2.

2.4 Presentation of qualitative analysis

We examined the selected studies, which included qualitative and quantitative encoding that provided information on the number of publications per year and the classification of the analytical approach used in measure identification. We went over the outcomes of all the papers chosen and presented a summary table of the key ideas for every selected paper. In Table. 1, a qualitative analysis of 20 selected papers has been presented.

ER anticipates a future educational trend that can help create opportunities for young learners by focusing on developing computational thinking and algorithmic skills (Wong & Jiang, 2019). For this purpose, there are several robotic kits available to learn with. The goal of using these kits is to develop problem-solving and creative critical thinking in young learners (Papadakis, 2020). One of the most popular approaches for instructing elementary students is to use LEGO Mindstorms EV3 robotic kits. They help introduce robotics courses, programming, and inquiry-based

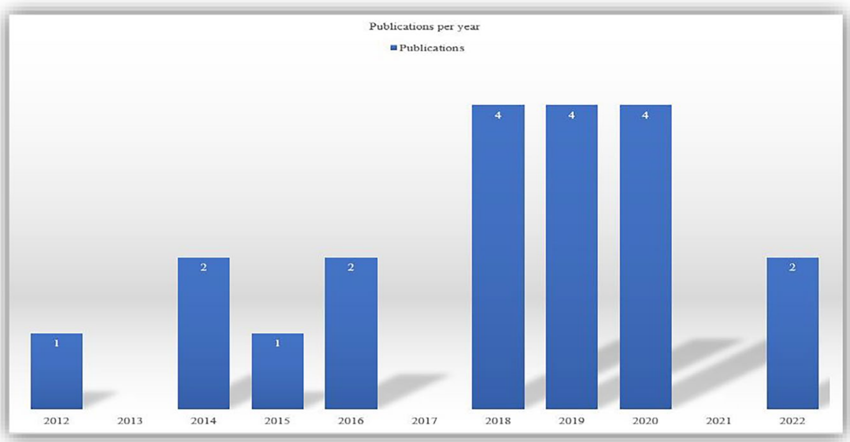

Fig. 2 Publications per year (until 30 November 2022)

Table 1 A summary representation of selected studies

The aim of the study	Source
The study's goal is to investigate how scenario-based learning can help develop creative thinking for problem-solving. The study's findings have a positive impact on learners, motivating them to find different solutions to uncertain situations and increasing their desire to learn STEM.	(Demir Kaçan & Kaçan, 2022)
The study investigates the effective integration of computational thinking and educational robotics into project-based learning (PBL) strategies, highlighting key abilities for the twenty-first-century workforce while promoting an in-depth understanding of STEM concepts.	(Pou et al., 2022)
This paper presents a list of existing robot construction kits of several types that could be used for educational purposes in young learners.	(Papadakis, 2020)
The study shows how a Cozmo robot can be used to teach mathematical concepts and develop a curriculum for young learners and has shown significant results, particularly at the school level.	(Ahmad et al., 2020)
The study intends to investigate how a multifaceted robotics-based intervention affected elementary-aged students' interest in STEM. Data analysis and evaluation reveal a positive effect on learners.	(Hudson et al., 2020)
The study's goal is to observe if robots could have a positive learning impact, and the results show that a social robot can perform a teaching task, and expressive robots can help with vocabulary and oral language skills.	(Konijn & Hoorn, 2020)
This study briefly described the validity evidence of the score generated by the measurement tool S-STEM to evaluate the changes in students' attitudes during an educational interposition in a middle school robotics learning environment.	(Luo et al., 2019)
The study investigates the outcomes of a STEM-based course to encourage students and increase their interest. The ARCS (Attention, Relevance, Confidence, and Satisfaction) framework was utilized for evaluating students' motivation levels using IMMS (Instructional Material Motivation Survey). As a result, motivation remained high throughout the period.	(Julià & Antolí, 2019)
The research is intended to gaze into the impacts of project-based learning on students' computational thinking skills and perceptions of STEM skills. The authors could not find a significant difference in the control and experimental groups' outcomes, respectively.	(Karaahmetoğlu & Korkmaz, 2019)
The research investigates the effects of learning programming, computational thinking, algorithmic thinking, and debugging skills at the primary level. The results show that such learning improved the student's ability to analyze problems and debug errors in programs.	(Wong & Jiang, 2019)
The purpose of this paper is to assess the interest of Malaysian students in STEM. According to teachers, elementary school students responded positively to the Kolb-based STEM module and building robotics prototype.	(Zainal et al., 2018)

Table 1 (continued)

The aim of the study	Source
The goal of the study is to broaden the concept of STEM as a multidisciplinary and social learning territory by utilizing human-centered robots (HCR). According to the findings, students were enthusiastic and encouraged to actively participate in HCR design and connect it to their areas of interest.	(Gomoll et al., 2018)
The study's aim is to investigate elementary students' learning performance and attitudes in the maker education program (Robot MakerSpace). Although the study was conducted at the elementary level, educators could modify the proposed curriculum program for other educational levels.	(Chou, 2018)
The purpose of this study is to investigate the students' working patterns, their achievements, the difficulties they face during STEM-oriented robotics courses, and the impact on students' motivation to learn. The findings indicate that students need to gain additional knowledge and skills before tackling the project's complexities.	(Barak & Assal, 2018)
This article discusses the various difficulties regarding STEM education and focuses on educating pupils with future-demanding skills, particularly at the elementary level. Additionally, share opinions on STEM for children.	(Smyrnova-Trybulska et al., 2016)
The primary goal of this study is to examine how elementary school students work together to solve complex problems. This experiment produced positive results.	(Chaudhary et al., 2016)
The study investigates young students' attitudes toward learning ER in STEM, with a focus on the FLL (FIRST LEGO League) competition. A positive shift in the attitudes of students, teachers, and parents, particularly females, was observed.	(Kaloti-Hallak et al., 2015)
This research's main goal is to increase students' motivation and develop an interest in STEM. They also attempted to involve underrepresented groups in summer camp activities. In the end, this activity yielded positive results; they successfully engaged the participants' parents.	(Mohr-Schroeder et al., 2014)
The study's goal is to investigate the issues surrounding ER training camps and to discuss the factors that should be considered when establishing such camps. The primary goal was to draw attention to the issues that the children encountered during the activity.	(Ucgul & Cagiltay, 2014)
The study investigates the impact of an after-school robotics course based on LEGO Mindstorms at the elementary level. The results show that the robotics club improved students' skills and changed their attitudes toward robots. It is an extremely useful tool for teaching scientific topics to students.	(Cavaş & Kesercioğlu, 2012)

robotics activities related to socio-scientific issues (Cavaş & Kesercioğlu, 2012). Similarly, Arduino project-based educational robots have a significant role in ER and in developing STEM skills (Karaahmetoğlu & Korkmaz, 2019).

The project-based learning (PBL) assists students in dealing with complex problems, collaborating, and as well as developing communication and understanding to attempt a solution (Smyrnova-Trybulska et al., 2016). The PBL approach also enhances computational thinking skills, problem-solving, coding, and computer programming skills (Pou et al., 2022). Moreover, considering environmental factors and gender differences, learning through robotics has an intrinsic and extrinsic impact on students' attitudes, motivation, and efficiency (Kaloti-Hallak et al., 2015). Robots can successfully educate school-level children, and social and teleconferences assist scenarios for learning STEM concepts. They can assist young learners in solving real-world problems, and many solutions to problems that arise in a proposed scenario (Demir Kaçan & Kaçan, 2022).

Having the primary goal of increasing public understanding of this multidisciplinary field, students can benefit from the HCR learning experience by understanding the social and technical aspects of STEM. A problem-based HCR curriculum is advantageous for students to attend and work through these aspects (Gomoll et al., 2018). Robot tutors have been proven effective in education and social perspectives and teleconferences assisting in teaching-related tasks. Study shows that students who are taught by robots perform significantly better (Konijn & Hoorn, 2020). An example of robotics assistance, Cozmo is a social robot that teaches mathematics to young students, and its use aids in understanding algebra, geometry, and trigonometry concepts (Ahmad et al., 2020). It is therefore essential for teachers and students to believe in the importance of STEM education for young learners and have concerns about STEM-related issues, especially at the elementary level since the enthusiasm for STEM education activities is growing.

There is also evidence that when used in a specially designed course, long-term STEM-based activity positively impacts a student's motivation. The IMMS, which is based on ARCS, could be used to assess whether students are motivated to solve problems in class using real-world objects, and STEM courses can improve learners' attitudes toward scientific fields (Julià & Antolí, 2019). For instance, STEM activities like summer camps encourage secondary school students to pursue STEM careers. This effort raises parents' awareness about the importance of STEM, serves as a guideline for student's interests, and helps them to make career decisions (Mohr-Schroeder et al., 2014). Design considerations for ER training are also critical factors to consider when developing summer camps. These activities' main challenges include camp design themes, instructional issues, group size, various technical problems, coaching, and competitions (Ucgul & Cagiltay, 2014).

In the future, computational thinking, problem-solving skills with the ability to deal with complexity, project management, and teamwork will be required. Communication skills are needed to handle complex problems, collaborate, and develop understanding to try to solve them. Recognizing the importance of updating the curriculum and improving aspects of teaching methods, the P3 Task Taxonomy (practice, problem-solving, and project-based learning) can be used to design class activities that investigate working patterns and achievement. Furthermore, it can encourage students to learn ER and attract them to the STEM field (Barak & Assal, 2018).

3 Educational Robotics (ER) for skill development

A systematic review of selected papers found that ER promotes the development of a variety of skills in young learners, including (1) creativity, (2) critical thinking skills, (3) analytical thinking skills, (4) computational thinking skills, (5) programming skills, (6) project-based learning skills, (7) scenario-based learning skills, (8) problem-solving skills, (9) algorithmic skills, (10) reasoning skills, (11) communication skills, social skills, (12) teamwork skills, self-confidence, collaboration skills, (13) Motivation, (14) logical thinking skills, (15) cognitive and learning skills, (16) process-oriented skills, (17) intellectual mega-cognitive skills, (18) independent learning skills, (19) STEM skills, (20) soft skills, (21) inquiry-based learning skills, (22) positive attitude, and (23) engineering skills. (Table 2).

Table 2 ER in STEM as a tool for developing various skills

Skills	Source
Creativity	(Valko & Osadchyi, 2021)
Critical thinking skills	(Zhong et al., 2022; Tsoy et al., 2018; Valko & Osadchyi, 2021)
Analytical thinking skills	(Amo et al., 2021)
Computational thinking skills	(Anwar et al., 2019; Chaudhary et al., 2016; Kopcha et al., 2017; Pou et al., 2022; Sáez López et al., 2021; Wong & Jiang, 2019)
Programming skills	(Pou et al., 2022; Scaradozzi et al., 2015)
Project-based learning skills	(Pou et al., 2022; Zdešar et al., 2017)
Scenario-based learning skills	(Demir Kaçan & Kaçan, 2022)
Problem-solving skills	(Kopcha et al., 2017; Sáez López et al., 2021; Valko & Osadchyi, 2021; Chaudhary et al., 2016; Karaahmetoğlu & Korkmaz, 2019)
Algorithmic skills	(Karaahmetoglu, 2019), (Karaahmetoğlu & Korkmaz, 2019)
Reasoning skills	(Papadakis, 2020)
Communication skills, social skills	(Rubinacci et al., 2017)
Teamwork skills, self-confidence, collaboration skills	(Zhong et al., 2022)
Motivation	(Kaloti-Hallak et al., 2015; Mohr-Schroeder et al., 2014; Julià & Antolí, 2019)
Logical thinking skills	(Sáez López et al., 2021; Karaahmetoğlu & Korkmaz, 2019)
Cognitive and learning skills	(Kubilinskiene et al., 2017; Valko & Osadchyi, 2021)
Process-oriented learning skills	(Jung & Won, 2018)
Intellectual-mega cognitive skills	(Sáez López et al., 2021)
Independent learning skills	(Abidin et al., 2021)
STEM skills	(Dochshanov & Lapina, 2019; Amo et al., 2021)
Soft skills	(Rubinacci et al., 2017)
Inquiry-based learning skills	(Smyrnova-Trybulska et al., 2016)
Positive attitude	(Kaloti-Hallak et al., 2015; Smyrnova-Trybulska et al., 2016)
Engineering skills	(Chaudhary et al., 2016)

It should be noted that creativity, analytical thinking skills, scenario-based learning skills, algorithmic skills, reasoning skills, communication and social skills, teamwork and self-confidence skills, process-oriented skills, intellectual mega-cognitive skills, soft skills, inquiry-based learning skills, engineering skills are only mentioned once in our literature review. Two studies mention programming skills, project-based learning skills, cognitive and learning skills, logical thinking skills, motivation, STEM skills, and positive attitude skills. Three articles mention critical thinking skills and motivation. Five studies have mentioned problem-solving skills, and six studies talk about the enhancement of computational thinking skills through the introduction of ER.

4 Discussion

The robotics learning environment is actively linked with two strong and central theories that have been influencing science education since the mid-twentieth century. One is the constructivism (Piaget's, 1960) theory about how people learn, which expresses learning as a process in which people construct their understanding and knowledge of the world by experiencing things and reflecting on these experiences. The other theory of constructionism (Harel & Papert's, 1991) proposed that people construct their knowledge in a social environment.

According to constructivism theory, ER assumes an active involvement of students in a process of learning that occurs because of mental construction by the learner. The ability to solve problems and deal with complexity, and work as a team, will be required in the future. Students must hone their skills to an elevated level to face the challenges of globalization and the economy. The twenty-first-century demanding skills can be developed in children while teaching them the fundamental concepts of robotics, which are essential for STEM disciplines, as demonstrated in Table 2.

Considering the importance of STEM in ER for young learners, three important research questions arise: what skill-set ER enhances in young learners, what impact does robotics intervention have on young learners, and whether if ER facilitates STEM education? These questions are addressed below.

4.1 Skill-set enhancement in young learners through ER

ER is a multidisciplinary field that includes aspects as diverse as mechanical structure design, construction, and operation of robots and robotic kits, as well as the possibility of applying engineering and mathematics, physics principles, and many other science subjects (Papadakis, 2020). Several studies show that ER has a positive impact on learning skills, as well as outcomes that show improvements in knowledge and a positive change in one's attitude and practical skills (Zhong et al., 2022). Robots and robotics kits can be used to teach engineering, mathematics, and a variety of science disciplines (Papadakis, 2020). They improve learners' analytical thinking (Amo et al., 2021), computational thinking (Anwar et al., 2019), problem-solving (Kopcha et al., 2017), cognitive learning, and logical (Sáez López et al., 2021), as well as their attitude toward learning by doing. Hands-on, minds-on learning is an ER learning tool that enhances the student learning experience (Scaradozzi et al., 2015). This provides a learning environment to promote knowledge-building activities related to STEM subjects, coding activities, and engineering concepts. There are several robotics kits available to teach young learners and provide a learning environment to engage them with STEM and engineering to concrete concepts (Papadakis, 2020).

Learners not only learn how technology works while designing, constructing, programming, and documenting autonomous robots and robotics projects. However, they also benefit from the opportunity to apply their skills in a learning environment in a valuable and inspiring way. For example, NAO (Akalin et al., 2013) is an autonomous and programmable humanoid robot developed by Aldebaran Robotics that has been used in various educational settings since 2007, including the RoboCup Soccer League (Miller & Nourbakhsh, n.d.), to develop algorithms for humanoid soccer and autism research. Different robotics kits are also supported in the educational field; students can understand the basic parts of robots with the help of these available kits, which can reshape STEM education in schools (Papadakis, 2020). These kits are useful for developing knowledge and competence in computational thinking in primary schools. Several elementary schools use LEGO Mindstorms (Papert, 1998) EV3 kits and visual block programming which are powerful tools for engaging student activity and developing computational concepts in young learners (Sáez López et al., 2021).

4.2 The impact of robotics intervention on young learners

Our second finding of this review is to investigate the effect of robotics intervention on young learners. ER is a powerful tool for grasping STEM concepts. Robotics is an all-in-one tool for teaching students, practical skills, knowledge, and the ability to work in a team, as well as developing an attitude and generating interest in the STEM field. Teaching robotics allows students to gain hands-on experience and understanding of technological and mechanical systems, as well as accept and adapt to changes brought on by complex environments and apply their knowledge in the real world, proposing it as a novel solution to real-world problems (Jung & Won, 2018).

In fact, robotics can engage students in learning by allowing them to construct new knowledge based on their experience while performing specific tasks. Learning engagement in this environment encourages students to acquire the skills and knowledge required to complete projects related to their interests. Most STEM activities play a key role in formal education for school-age students. This educational approach allows students to improve their logical thinking, creativity, curiosity, and critical thinking. Hands-on experience is "learning by doing" (Dewey, 1887), and it aids in the retention of what we have memorized. Constructionism is building the process of thinking, generating a physical model, and learning by engaging learners in a process-oriented task (Anwar et al., 2019). It also provides equal opportunity to all learners which increases their interest in the learning environment. Training with educational robot kits in schools is carried out using these techniques which are proven to develop knowledge and competence in computational thinking in young learners. The international FLL is a popular ER and STEM competition designed to pique learners' interest and assist them in deciding on a career path (Graffin et al., 2022). These robotics competitions have a positive impact on students and help to improve students' attitudes toward learning. Robofest (Miller & Nourbakhsh, n.d.) has something for everyone, incorporating STEM, coding, and programming to promote hands-on learning.

4.3 ER facilitates STEM education

STEM is a popular educational field and is considered a high priority in the modern era because it helps to improve multiple skills, computational thinking, problem-solving, teamwork, and self-confidence. ER considers an upcoming educational trend, an innovative tool assisting in the implementation of STEM education in schools and creating opportunities for young learners, helping them in making career decisions, and making subjects relevant in context to real-world problems. ER is quite a promising approach for both students and teachers (Mohr-Schroeder et al., 2014). Because of its hands-on nature and integration of technology, it facilitates an amusing and enthusiastic learning environment (Kopcha et al., 2017).

ER is considered an exceptionally rich field with numerous opportunities to integrate not only STEM but also several other disciplines, such as literacy, social studies, dance, music, and art, while also providing the opportunity to search for ways to work together to foster collaboration skills (Scaradozzi et al., 2020). ER can introduce young learners to a variety of multidisciplinary fields, ranging from STEM to social skills. Today, the approach of using ER to develop a wide range of skills can help expand it at the elementary and secondary school levels. Furthermore, learning by doing, problem-based learning, scenario-based learning, and problem-solving skills in uncertain situations encourage students to be more aware of how a problem in society can be solved with the help of science, and to learn more complex concepts that require more high cognitive ability in a relaxed manner. These are the reasons why the incorporation of ER into STEM concepts is so important in elementary and secondary education.

The training of teaching ER to future teachers is an important part of this educational effort because teachers' roles in STEM education extend beyond the classroom and include extracurricular activities such as festivals, competitions, and workshops (Valko & Osadchyi, 2021). Robotics is not currently part of the curriculum in the educational field; it is developed as an extracurricular activity with a specific method during teaching and learning. The future possibility of teaching robotics using the existing framework curriculum is being considered. The Finland educational system, for instance, places a greater emphasis on practical skills and disregards the traditional mechanisms for developing curricula and assessing students' learning styles. There is no need for a top-ten list. It is not a competitive environment, with collaboration as the standard. As a result, students in Finland outperform students in the rest of the world regarding academic performance. Students play an active role in shaping future technology and ER support to promote STEM education because it introduces complex mathematical and scientific inquiry mechanisms, as well as problem-solving skills.

Researchers discovered that students in STEM programs have greater chances to learn through experimentation. But we need more inventiveness and creativity in our economy. STEAM is a way to use STEM as a tool and integrate STEM concepts with the arts for this aim. It is crucial in a way that prepares students for a diverse cultural environment and a technologically driven world. This multidisciplinary method provides a better grasp of science and technology, its significance, and its contribution to the economy while improving students' self-efficiency.

The implementation of this interdisciplinary approach has recently entered formal and informal education in elementary and secondary schools. Nowadays, there is a growing movement of digital fabrication laboratories all over the world. Artificial Intelligence (AI) also demands consideration for its use in ER to assist in the introduction of STEM concepts and skills found in other curricula. In short, in the future, AI will be mixed with robotics, and autonomous vehicles and smart cities will be commonplace, robots will be an essential part of daily life. Considering the current and future frameworks, policymakers have recognized that introducing scientific concepts at the school level will be critical to meeting future needs. As a result, we hope this educational mechanism will help with a smooth future digital transition and transformation. Diversity in terms of age, gender, and school was one of our goals because we wanted students from various backgrounds, cultures, and experiences to collaborate.

5 Conclusion

This study reviews the published literature on the importance of ER in STEM education for young learners in elementary and secondary schools. In this regard, we reviewed the effectiveness of ER in understanding STEM concepts in 20 articles. These articles present qualitative and quantitative evaluations and analyses of this interdisciplinary field's potential in young learners.

Based on our three research questions for this systematic review, we concluded that ER aids in understanding STEM concepts and contributes to learning scientific and technical skills through robotic kits. The findings of the articles also conclude that ER is a tremendously powerful tool for promoting STEM awareness, providing opportunities to concrete scientific concepts related to mathematics, computer science, and programming.

Our study identifies new research directions that will focus on implementing programming approaches to create a mindset for future development. However, we face challenges such as a lack of awareness, resources, and student interest in science and mathematics. Furthermore, evidence suggests that ER effectiveness in STEM education has positive outcomes. As a result, much effort must be expanded into teaching STEM-related concepts to the underrepresented population while also making it enjoyable. Short-term activities, such as outreach, after-school, and summer camp activities with a short-designed curriculum, must emerge from this constrained framework, and an environment must be created to influence positive attitudes and motivation in students.

Based on the findings of this systematic review, educational robots are beneficial for the general development of multiple competencies and cognition at an early age and complement a better understanding of STEM concepts.

Data availability Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

The authors have no relevant financial or non-financial interests to disclose.

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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