Robotics in the Context of Primary and Preschool Education: A Scoping Review

Eleni Mangina, *Senior Member, IEEE*, Georgia Psyrra, Laura Screpanti, *Member, IEEE*, and David Scaradozzi, *Member, IEEE*

***Abstract*—This article presents an overview of educational robotics (ER) in primary and preschool education. As ER seems to be gaining popularity for its effectiveness as a learning tool, more research needs to be done in this area. Recent results from ER pilot projects advocate for the integration of ER in K-12 education curricula. On the other hand, teachers may face various difficulties in carrying out such activities due to lack of experience or knowledge in this field. Previous research has shown that ER is still an open field for exploration. Even though an increasing number of experiences are available for the use of robotic tools in early education, there is not enough empirical evidence on the features they need to present for young learners to perceive them as attractive and easy to use. In addition, the high cost of some tools may prevent educational institutions from using them systematically. To detect possible gaps in the current research, in the context of this work, 21 articles representing ER applications and frameworks were collected and reviewed between 2011 and 2021. The results of this study demonstrate that ER can be a valuable tool for supporting primary and preschool students. However, the review supports that more research is needed on the technical features that a robotic tool must have to be successfully introduced to students of this age. Moreover, future work is needed to develop low-cost ER tools so they can become more accessible to educational institutions.**

***Index Terms*—Educational robotics (ER), K-12, robotics applications and frameworks, STEM (Science, Technology, Engineering, Mathematics).**

I. Introduction

MANY countries have recently integrated educational robotics (ER) in primary and preschool practices as an optional subject. ER aims at exploring robotics fundamentals with and hands-on, playful approach, where students use robots for educational activities involving the construction and deconstruction of an artifact that can be programmed to accomplish a given task [1]. As an educational tool, ER holds the potential to develop many useful transversal skills, such as communication, problem-solving, teamwork [1], [2], [3], [4] and computational thinking (CT) [5], [6], [7]. It can be effectively used to increase students' interest and motivation in learning STEM (Science, Technology, Engineering, Mathematics) subjects [1], [2], [8], [9] and also to boost inclusive education and prevent early school leaving [10], [11]. Introducing robotics early in the school curriculum can improve cognitive and learning abilities in preschool children [12], can support CT development [13], [14], [15], can help create a fun and exciting learning environment [16], can support engage students in STEM activities [16], [17], and can enhance student's "critical thinking, computational thinking, problem-solving, algorithmic thinking, creativity, and collaboration" [13].

Despite the many benefits pointed out by researchers worldwide, ER is not systematically integrated with early education. The reasons may be connected with the lack of studies evaluating evidence about ER in education [1], [2], the heterogeneity of activities, tools, and methods characterizing ER intervention [1], [2] and the lack of focused research on ER in early childhood education (preschools and primary education) [16], [17]. To better define the extent of this potential gap, the present work intends to identify recent trends in the scientific literature about ER in early childhood education. To achieve that the authors collected and thoroughly reviewed ER applications and frameworks published between 2011 and 2021. The review mainly highlights the evaluation methods and strategies used by the collected ER studies, the characteristics of the pilot groups, the type of robotic kit used, the effectiveness of applications, and the difficulties revealed by the participants.

The rest of this article is organized as follows. Section II presents a comprehensive literature review of relevant work that has been recently published. Section III illustrates the methodology used to conduct this review. Section IV reports the results derived from the selected studies. The findings are discussed and compared with previous studies in Section V. Recommendations for future work on supporting the use of ER in early education are also provided. Finally, Section VI concludes this article.

II. Background

Research has shown that robotics has great potential to be implemented in the context of all levels of education, including K12 (shortening of kindergarten through 12th grade) [18]. As a consequence, the field of robotics in education is a rapidly evolving topic and has seen an increase in recent years (see Fig. 1) [9], [19]. As a side effect of this increase, also the number

Manuscript received 3 August 2022; revised 7 February 2023 and 1 April 2023; accepted 6 April 2023. Date of publication 12 April 2023; date of current version 4 January 2024. This work was supported by the European Erasmus+ program: RoboPisces - 2019-1-IT02-KA201-063073; Key Action: Cooperation for innovation and the exchange of good practices; Action Type: Strategic Partnerships for school education. *(Corresponding author: Georgia Psyrra.)*

Eleni Mangina and Georgia Psyrra are with the Department of Computer Science, University College Dublin, D04 V1W8 Dublin, Ireland (e-mail: eleni.mangina@ucd.ie; Georgia.psyrra@ucd.ie).

Laura Screpanti and David Scaradozzi are with the Department of Information Engineering, Università Politecnica delle Marche, 60131 Ancona, Italy (e-mail: l.screpanti@univpm.it; d.scaradozzi@univpm.it).

Digital Object Identifier 10.1109/TLT.2023.3266631

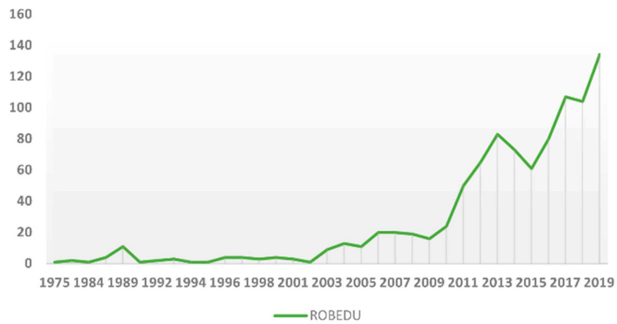

Fig. 1. Scientific production related to the term "robotics" in education (ROBEDU) retrieved from the database Web of Science over the years. Copied from [9].

of literature reviews has grown in the past years. Searching the Scopus and Web of Science databases (keywords: "Robotics" AND "Education" OR "educational Robotics"), the authors identified 42 reviews about robotics applications in the field of education published in relevant indexed journals from 2011 to 2022. Results are summarized in Table II given in the Appendix. Notably, only 8 reviews out of 42 focused on ER and early childhood [4], [15], [16], [17], [27], [31], [34], [45]. Similarly, researchers in [3] and [29] pointed out that there are not enough review articles about ER for ages from 6 to 12 years. The analysis of the existing reviews about ER in early childhood education seems to support that statement because it highlighted that they either provide evidence only for a narrow age group in early childhood [15], [16], [17], [34], [45], or limit their investigation to a specific ER application like STEM education [17], [34], use of the robotic toolkit [4], [27], [31] or development of CT [45], or miss the recent advances in the field [4], [27], [31].

More specifically, Toh et al. [4] reviewed studies published between 2005 and 2016 to find out the most used study design, how the robot use influenced child behavior and development, how the stakeholders perceived the use of robots in education, and how children reacted to robot design or appearance. Jung and Won [27] investigated studies published between 2006 and 2017 about robotics education using robotics kits (not social robots) for young children (Pre-K and kindergarten through the 5th grade) to find the theoretical and methodological traits of robotics education. González-González et al. [31] reviewed all the tools that are "tangible devices," including robots, and that were used by researchers in early education worldwide from 1968 to 2018. They found that the main tangible technology used in childhood education is the tablet and robotics is very important to work on coding, STEAM, gender, and CT in early childhood. Although these studies provide useful information about ER tools, they do not provide evidence of the current state of ER in early education for the period 2019–2022.

More recently, five additional reviews were conducted in the field of ER in early childhood education, including recently published studies. All but one, focus on selected age groups of students in K12 or at preschool level. In particular, Çetin and Demircan [34] synthesized the findings proposed by studies focusing on programming experiences through robotics for children, between the ages of zero and eight, and for pre- or in-service teachers of early childhood education. The aim was to reveal the possible contributions of robotics programming to the integration of technology and engineering in STEM education. Chaldi and Mantzanidou [15] aimed at finding out whether preschoolers (aged 4–5 years old) can operate, program, and control an educational robot and whether educational robots can support STEAM education leading to new ways of learning. Kyriazopoulos et al. [16] explored the main findings about ER in primary education to find out where the learning happens and in which respect. Their findings reported that the majority of ER activities took place in a formal learning environment and that ER is appropriate for teaching subjects of STEM education. It also highlighted that despite the positive cognitive and affective outcomes of ER in learning, there are aspects that require further investigation. Bakala et al. [45] analyzed ER interventions and experiences that could promote CT during early childhood (children between 3 and 6 years old attending pre-primary school education level) focusing on the evaluation process of CT. Results reported a need for this area of study to mature through more rigorous reporting of research experiences and consistent approaches to evaluate CT. Despite the valuable contribution of the aforementioned studies with regard to ER, none of them provide evidence for a wider age group corresponding to early education (e.g., between 4 and 12). It seems that out of the five recently published reviews about ER in early childhood education, only Tselegkaridis and Sapounidis [17] explored available studies about ER in STEM education with participants aged between 3 and 12. However, 66% of the selected studies involved participants being older than 7. Findings highlighted that usually a nonexperimental design approach is applied; that not always an evaluation is reported, and that it is not safe to generalize the results of the studies as long-term research is restricted.

The picture deriving from the analysis of the state-of-the-art of ER in early childhood education suggests that only a few studies focus on ER in early childhood education and none of them aim to provide a broader and more inclusive view on the field.

Overall, the analysis of the latest scientific literature showed that there is a lack of comparable research that focus clearly on ER as defined in [1], there are only a few studies about ER in early education (preschool and primary education), and there is a lack of studies focusing on the broader context of ER in early education. The present work aims at covering the gap by reviewing studies published between 2011 and 2022 that report ER experiences in early education in a broad context. The present review will answer the following research questions (RQs):

RQ1. What is the current state of ER applications in the broad context of early education?

RQ2. What kind of frameworks have been recently published to support early robotics education?

The term "early education" is used by authors to describe preschool and primary education, namely participants in the studies are pupils aged between 4 and 12 years.

TABLE I
INCLUSION CRITERIA

P-Population	The review focuses on students aged 4–12 as well as teachers, methods, and materials involved in robotics activities in K-12 education.
C-Concept	The main idea of the review is to explore the current state of utilization of ER, by reviewing relevant applications and frameworks.
C-Context	The review aims to scope how ER is conducted recently (2011–2021) in K-12 education worldwide, the reflection on its implementation as well as its effectiveness.

The term "framework" is used here to depict all those models and methods that support the integration of educational activities using robotics.

The present literature review intends to identify and analyze knowledge, and to identify key characteristics of ER in early childhood education. Since the body of knowledge in the field of ER in early childhood education is heterogeneous and the aim of this article is to provide an overview of the available knowledge, authors chose to conduct a scoping review following the guidelines provided in [53] and [54].

III. METHODS

This study was conducted following the guidelines of the 2018 PRISMA framework for scoping reviews [54], which provides a set of rigorous and transparent methods to ensure trustworthy results. The aim of the present study is to collect and present in a structured and efficient way an overview of the evidence of the educational use of robotics in Primary and Preschool education.

A. Eligibility Criteria

The Population–Concept–Context (PCC) [53] framework recommended by the Joanna Briggs Institute for scoping reviews was used to enhance the search strategy for the identification and evaluation of relevant literature based on the eligibility criteria as shown in Table I. The review aims to collect only recently published studies so that the analysis could present the trends of ER in the context of primary and preschools in the last decade (2011–2021).

The exclusion criteria are as follows:

1) the study is not peer-reviewed;
2) the study is not written in English;
3) the study is a literature review;
4) the study is not relevant to the use of robots for educational purposes;
5) the study is not focusing on preschool or primary education;
6) the study is focusing on programming virtual environments rather than physical mechatronic devices.

B. Information Sources

The four scientific databases were considered during the initial phase (seeFig. 2): ScienceDirect, IEEE Explore Digital Library, Springer Link, and ACM Digital Library. Each database

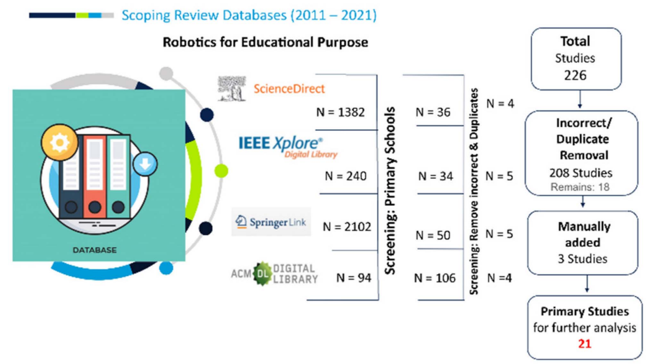

Fig. 2. Summary of Scoping Review databases.

includes relevant studies about robotics in education. The search strategy included limiting the search results to studies that were published between 2011 and 2021 and that were written in English. The keywords chosen to identify the relevant records were "robot," "primary school," "pre-school," "early education," "framework," "applications," "pilot," "case study," "coding," "computational skills," and "STEM."

C. Search and Selection of Resources

The initial search on those 4 databases returned 3818 papers. The titles and summaries of these papers were screened to exclude irrelevant works. As a result of this first screening, 226 papers were selected and considered for the next screening phase, which included a full review of the articles to check whether the eligibility criteria were met. Finally, 21 unique and fully accessible studies were identified as primary sources for further analysis in this review. Details about the number of records retrieved by each scientific database as well as the process of the data extraction and monitoring are shown in Fig. 2.

D. Data Items

Each selected article was indexed in a local database and, for each study, the following characteristics were included: title, country, year, purpose, software and hardware use (where possible), methods, evaluation metrics, relevant findings, and evaluation/assessment strategies. Such characteristics were deemed relevant to reach the aim of the present work. The purpose of the study was deemed relevant because it brings information about the type and the scope of the study. The tools and methods were deemed relevant because they demonstrate the strategies that researchers apply when using robots in the context of early education. Finally, the evaluation strategies and the main findings of the studies were considered relevant to show the general trend in the use of robotics in the early education context as well as the impact and effectiveness of such strategies.

E. Synthesis of Results

The collected literature was analyzed based on whether the selected articles demonstrate a robotics application or a framework for early education. In this way, the authors of this

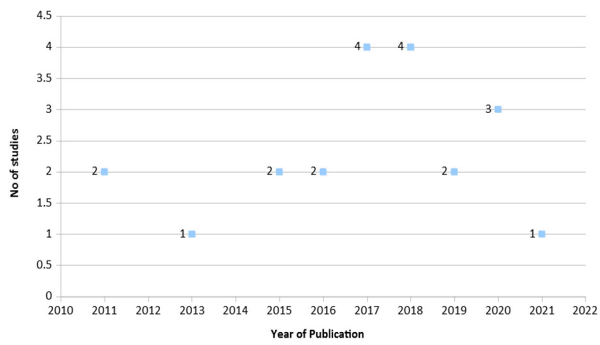

Fig. 3. Year of publications.

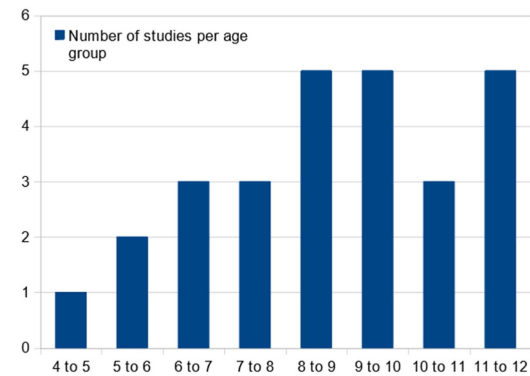

Fig. 4. Number of studies per age group.

study aimed to capture the current state of robotics applications piloted in the context of early education and at the same time to explore the support provided by recent reliable frameworks and implementation approaches in this field. Furthermore, the applications were also classified based on the robotic hardware used, the methods they applied, and the age/grade of the recruited participants.

IV. Results

Fig. 3 shows the distribution over the years from 2011 to 2021 of the 21 selected studies.

The articles that explore the impact and effectiveness of using robots for educational purposes in children aged 4–12 years and how students of this age interact and accept robotic technology were characterized as applications. Table III given in the Appendix illustrates the main features of these studies. The relevant articles, in addition to presenting the effects of educational intervention using robotics, highlight the various approaches and methods.

The articles attempting to present models that support educational activities for young students using robotics, as well as proposals for innovative and effective methods to integrate robots in early education were characterized as frameworks. Table IV given in the Appendix shows the main features of the studies presenting frameworks for the implementation of robotics education in preschool and primary education.

RQ1. What is the current state of robotics applications in the context of early education (preschool and primary education)?

Table III given in Appendix presents the details of the studies presenting an application of robotics in early education ($n = 12$): aims and methodology, the age range and number of students involved in the study, nationality of participants, the type of robotic kit used and the main findings.

The collected applications showed that robotics is applied in various activities in early education, either to support robotics and STEM-related activities or to develop different skills. Specifically, 5 out of 12 collected applications utilized robotics as a mean to develop executive function skills [12], to support the development of students' spatial abilities by involving them with a robotics mathematics course [57], to carry out learning activities about scientific research [58], to support the development of social and cognitive skills as well as to promote the access of children from low-income families to technology [62], and to provide chances of self-regulated learning with the help of a robotic tutor [61].

The use of robotics in early education was additionally applied to conducting STEM-related activities. Specifically, 10 out of the 12 collected applications tested robotic technology to advance students' technological literacy [55], to enhance technology attitudes and self-efficacy [64], and to conduct activities around the topics of electromagnetism [56], [62], scientific research [58], problem-solving, planning, CT, and programming [12], [59], [60], [63], [64], [65].

All the applications showed that robotics in early education can be used as an effective tool to enhance learning. By stimulating students' motivation and interest [65], [67], [68], it can support students in developing a variety of skills such as self-regulated learning [61], executive skills [12], CT [59], [60], [63], and problem-solving [57], [60], [65]. It can also improve students' learning outcomes in programming [42], [45], [46], [48] and other areas not related to robotics.

To evaluate the effectiveness of the integration of the robotic tools in early education various methods are applied, including analysis of video and images taken during the activities [55], [57], [58], data scanned with the help of the robotic application [56], teachers' observations [57], interviews with teachers [59] and students [64], surveys with the students [62], [64], [65] and teachers [59], and standardized domain assessments [12], [56], [60], [61], [62], [63].

Regarding the age groups targeted by recent robotics applications, it appears that only a few studies have tested robotics in kindergarten education for children between the ages of 4 and 6 (see Fig. 4). Specifically, only two studies targeted students of this age, and both did not appear to involve them in actual coding activities but through playful interaction with robotic kits instead [12], [64].

Most of the collected applications (10 out of 12) employed robotic kits to involve students in programming and construction activities [12], [55], [56], [57], [59], [60], [62], [63], [64], [65]; the rest used the robotic technology as a means to learn about scientific research [58] or to support self-regulated learning [61].

Furthermore, most of the applications (9 out of 12) employed robotic tools from known educational material manufacturers, which may raise the cost of applications. Specifically, most of the

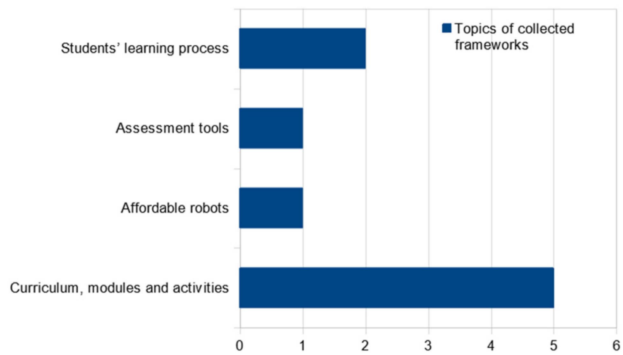

Fig. 5. Topics of the collected frameworks.

collected applications employed LEGO WeDO kits [59], [60], [63], [65], Lego Mindstorms NXT robots [55], [61], Fischertechnik robotic kit sets [57], Bee-Bot [12], Aldebaran Robotics NAO torso [58], and Dash Robot [65], whereas two studies provided students with hardware electronics elements, such as electric circuits kits and Arduino MEGA [56], [62] and only one did not mentioned the type of the robot [64].

Finally, despite the effectiveness demonstrated by the collected applications, some studies reported that there were issues in implementing robotics in early education. For example, teachers were afraid to teach robotics [59] and faced many technical challenges in implementing activities [39], students aged 7–8 year old students were not willing to work with worksheets [45], the robotic kit was considered expensive for schools [45], the kits used did not demonstrate a good motor calibration [43], and finally the robots were considered to violate social rules due to technical reasons [46].

RQ2. What kind of frameworks have been recently published to support primary robotics education?

Table IV given in the Appendix presents the selected studies presenting a framework for the integration of robotics in preschool and primary education ($n = 12$). Objectives, methodology and main findings are reported, as well as details about the pilot implementation in the relevant environment.

The collected frameworks focus on various topics which are relevant to the robotics curriculum and to the design of corresponding modules and activities [66], [68], [69], [70], [71]. The frameworks also target the cost of robotics kits [67], assessment tools [5] and the exploration of students' interests and problem-solving paths during robotics activities [72], [73]. Fig. 5 presents the number of frameworks collected per topic.

With regard to robotics modules and the design of the educational activities, the collected frameworks present different approaches and scenarios: rescue robot construction workshops as part of a curriculum for primary and kindergarten education aiming at fostering attitudes on science, technology learning, and manufacturing [66], modules aiming at fostering AI literacy at all level of education following constructionism principles [68], challenge problems for primary school students by utilizing a robot simulation environment [52], a lab experience in a primary school class to explore how to bring IoT tangible design to children and their teachers [70], and a learning-training framework to support faculty on the design of modules and activities for the integration of robotics in primary schools [71].

Concerning robotics' hardware design, one single study of the collected frameworks presents the development of an affordable, simple, and easy-to-use robot for early robotics education [67].

The frameworks also feature a tool for assessing prerequisite CT skills in the context of robotics activities in primary and lower secondary education [5].

Finally, the rest of the framework studies focuses on exploring students' learning processes during robotics activities [55], [56]. They investigate and demonstrate how students' interest in programmable robotics develops and contributes to robotics creation [72] as well as what problem-solving pathways the students develop during robotics activities and how they utilize sensors in their solutions [73].

Most of the frameworks collected were also tested in schools to prove their effectiveness and be established as validated for early education. Only one framework did not report a validation study [71]; it proposed a guide to designing robotics modules and activities, then provided an example of implementation without the implementation of a pilot at school providing measures or evidence of its effectiveness. Finally, Scaradozzi et al. [73] demonstrated a machine learning approach for identifying students' strategies for problem-solving tasks in robotics education by deriving data from the implementation of robotics activities. The preliminary results encouraged the authors to include new classes in experimentation to continue validating the approach [73].

V. Discussion

The RQs defined in this scoping review aimed to investigate the recent status of robotics applications in K-12 education and how recently published frameworks can serve the needs of future relevant applications. The review was conducted based on a total of 21 peer-reviewed articles, published between 2011 and 2021, to provide evidence of the current state of robotics applications in early education. The collected articles were grouped according to whether they represent a robotics application or a framework for early robotics education. Further grouping was performed based on the objectives/topics of the studies, the robotic hardware material used, the applied methods, and the age/grade of the participants.

With regard to RQ1, overall, the results showed that the recent applications of robotics in early education are effective as a tool to enhance learning. Evidence suggests that the selected studies reported the use of robotic technology in both pure and multidisciplinary activities. Robots are used both to enhance students' knowledge about robotics and to develop STEM-related skills, such as problem-solving skills, computing, and programming skills. Moreover, robotic technology is also used as a mean to carry out non-STEM-related activities through which students can promote, for example, their social skills [62] or have opportunities for self-regulated learning with the help of a robotic teacher [61]. However, such studies were found to be only few. The application of robotic kits in multidisciplinary activities shows the potential of ER. Consequently, more research in this area is needed to support the application of robotic tools in non-STEM activities and to demonstrate their effectiveness. Overall, providing modern curricula with a full range of STEM-related activities as well as activities about non-STEM subjects like art, humanities, sustainability, and inclusion could help teachers engage students in meaningful activities. Moreover, the classification of the collected application studies based on the target age group of students revealed that robotics applications have been tested more on older students since eleven out of twelve studies focused on pupils aged six to twelve [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65] and only two studies focused to younger pupils (aged between 4 and 6 years) [12], [64]. This result confirms the general lack of studies focusing on early education and robotics [16], [17], thus opening up interesting questions about the effects of robotics education on young children's learning and how to evaluate the impact of robotics applications in an educational context on the development of young students.

In terms of evaluation strategies, the results of the studies about the applications of robotics in early education suggested several techniques to prove the effectiveness of the intervention. The majority of such assessments were based on the analysis of students' outcomes in standardized domain assessments [12], [56], [60], [61], [62], [63] and on the analysis of the audio and visual material that was captured during students' activities [55], [57], [58]. However, four studies out of twelve analyzed data derived exclusively from students' and teachers' surveys and interviews [59], [62], [64], [65]. As also stated by [27], it seems that existing research is finally focused on understanding which advantages await children who are engaged in robotics activities such as constructing and programming robots. These results seem to be different from the findings of [2], which suggested that there might be a lack of research with quantitative assessment of learning. Admittedly, the field of ER has evolved in the last ten years and research has started to investigate the effects of ER along different dimensions and from different perspectives, as also highlighted by the number of reviews published in the last ten years. However, there isn't still a final statement about the short-term and long-term impact of robotics applications in education.

Despite the effectiveness reported by many studies in the field, robotics applications still have some open questions. Results of the present work showed that four out of twelve studies raised issues about the implementation of robotics in early education [58], [59], [60], [64], like teachers' lack of knowledge and confidence, robotic kits' cost [59] and technical features.

Notably, nine interventions out of twelve were carried out mainly using commercial robotic material, as identified also by [1] and [30]. Eight of them employed robotic kits to involve students in programming and construction activities [12], [55], [57], [59], [60], [63], [65], while the rest used the robotic technology as a means for the development of transversal skills where the objective was not to teach robotics [39], [41].

With regard to RQ2, most of the collected frameworks provided validated work by testing their approach within school contexts. The majority of them were based mainly on curriculum topics providing approaches to the design and implementation of ER modules and activities, the learning process and student assessment providing accurate and evaluated pilot approaches [66], [68], [69], [70], [71]. Some other frameworks targeted on exploring students' learning processes during robotics activities [72], [73] while fewer approached issues related to low-cost robotic kits for early education [67] and the assessment of prerequisite CT skills [5]. Although it was not part of their primary objectives, two collected frameworks proposed approaches that could be used to support low-cost cost ER applications such as the fabrication of Internet of Things (IoT) tangibles [70] and the optional use of virtual robots [69]. Such approaches should be further investigated to support the use of low-cost ER activities. In terms of the lack of technical skills, a teacher-training framework [71] considered difficulties regarding the design of ER activities, though it did not consider technical issues that teachers may face during their implementation and how to overcome them. Given the topics raised by the collected frameworks in relation to the difficulties encountered in application studies, it can be concluded that there is a lack of recent frameworks that can facilitate the use of low-cost robotic kits and overcome the technical difficulties faced by students and teachers in conducting robotics applications.

As a whole, it can be observed that many of the challenges that were identified by previous studies, still need to be completely addressed, namely a shared definition of ER [1], sound validation studies [2], [21], and an agreement about the best robotics tool [21], [30].

VI. Conclusion

Overall, the results of this study revealed that ER in early education can be an effective tool for teaching various skills and subjects around the field of robotics as well as other not related fields. This finding is in line with previous research that explored the potential of robotics in the contexts of school and early education [1], [2], [29]. More specifically, robotics in K-12 education seems to support the development of a variety of skills such as self-regulated learning, executive skills and CT as well as to improve the learning outcomes in various subjects and to stimulate motivation and interest.

Previous research has shown that there is a lack of empirical evidence to support the effectiveness of ER, especially when it comes to students aged 11–12 [2]. However, there seems to be great potential for the implementation of robotics at all levels of education [18]. The present study confirms the applicability of robotics in early education since several robotics applications have recently been conducted for students of this age, thus filling the gap of the lack of robotics applications in students aged 11–12 years. However, the study also showed that the number of ER applications in students aged between 4 and 6 years is poor compared to other age groups related to K-12 education, thus highlighting the need for further research on ER in this particular age group.

As topics related to robotics such as CT and programming have been integrated into the schools' curriculum in many countries around the world [74], various frameworks have been published to support the successful implementation of robotics educational activities. The frameworks gathered in this study can support some of the needs presented by the collected ER applications, by providing innovative robotics curricula approaches, as well as modules and examples of early ER activities that can help teachers feel competent and confident in performing robotics activities in their classroom. The collected frameworks can also support teachers in assessing their students' skills as well as in improving their understanding of how students' interest evolves during robotics activities and what problem-solving strategies they apply.

APPENDIX

TABLE II
COLLECTED REVIEWS OF ER APPLICATIONS

Title	Year	Definition of the scope of the field of ER	Age range	Aim of the study
Exploring the educational potential of robotics in schools: A systematic review [2]	2012	the objective is not to teach robotics but using robotics as an educational means.	elementary middle, and high school	examine the state of research in schools, based on the subjects taught, evaluation methods, and findings
A review of the applicability of robots in education [20]	2013	not specified; however, the review considers the broad application of robots in education, namely robots as a learning/teaching aid and as a mentor/tutor (social robots)	not specified	find out the subjects of the Learning Activity, the places where the learning Take Place, the role and behavior of the robot during learning, the types of robots used, which are the pedagogical theories
Educational robotics: Open questions and new challenges [21]	2013	a branch of educational technology that creates a learning environment in which children can interact with their environment and work with real-world problems	not specified	review the diffusion across Europe of ER, the supposed development of 21st-century skills, the technology paradigm, and the validation of its impact
A review: Can robots reshape K-12 STEM education? [22]	2015	a tool for learning, which comprehends: the development of technical and non-technical knowledge by constructing and programming the robot, the cognitive and intellectual development of children through socially assistive robots, collaborative human-robot interactive learning, and robot-based mentoring	K12	review the learning activities and the learning platforms developed for teaching mathematics and physics in K-12 education
A review on the use of robots in education and young children [4]	2016	not specified, however, studies reporting robotics as a teaching subject, or the use of robots as assistive technologies are excluded	early childhood and lower-level education	assess the effectiveness of using robots mapping the design of studies, the influence on child behavior and development, stakeholders' perception, and children's reaction to robot design or appearance
Applying robotics in school education: A systematic review [23]	2017	not specified, however results include studies about social robotics and socially assistive robotics	formal primary, basic, and secondary schools and informal education, e.g. after-school activities, summer camps	Identify the benefits of using educational robots as teaching aids in various subjects. Present the diversity of teaching methods, aided by educational robots; Identify the prospects for scientific research related to robotics in education
Role and review of educational robotic platforms in preparing engineers for industry [24]	2017	not specified	not specified but mainly focusing on students enrolled in engineering courses	survey manipulator-based frameworks (both virtual tools and platforms employing a real robotic arm) with a focus on teaching and training of kinematics, dynamics, and controls
Robotics applications grounded in learning theories on tertiary education: A systematic review [25]	2017	broad robots' applications in education	tertiary education	identify the subjects that are taught through robotics and the learning theories underpinning the educational applications of robots
Educational robots driven by tangible programming languages: A review on the field [26]	2017	a new innovative tool for education and learning introduced in many schools with the scope to enhance higher level thinking skills and abilities and thus help students solve complex problems in other domains of knowledge; children build robotic entities and program by means of a simple programming language.	not specified	review tangible programming languages which are designed to program real robots and robotic mechanism
A systematic review on teaching and learning robotics content knowledge in K-12 [3]	2018	Robotics education in general	K12	review the empirical studies on teaching and learning robotics content knowledge
Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work [6]	2018	Educational robotics suggest learning through design and include activities such as constructing and operating robot platforms	K12	review the studies about the use of ER for advancing students' computational thinking
Systematic review of research trends in robotics education for young children [27]	2018	Robotics education using robotics kits (not social robots)	young children (Pre-K and kindergarten through 5th grade)	investigate the definition of robotics education, the thematic patterns of key findings, and the theoretical and methodological traits

TABLE II
(CONTINUED)

Title	Year	Definition of the scope of the field of ER	Age range	Aim of the study
Learning by Teaching with Humanoid Robot: A New Powerful Experimental Tool to Improve Children's Learning Ability [28]	2018	the use of humanoid robots with children as companions or tutors to apply the learning by teaching approach	not declared, but actually reporting studies that involved students aged 3–9 years	review existing literature about humanoid robot used to present the learning by teaching approach
A systematic review of studies on educational robotics [29]	2019	not specified	K12	review empirical studies to discuss the general effectiveness of ER, the development of students' learning and transfer skills, creativity, and motivation; the capacity to broaden participation; and the teachers' professional development
The effect of commercially available educational robotics: a systematic review [30]	2019	not specified	not declared, but actually reporting studies involving students from kindergarten to university	examine 29 commercially available ER products to find out the extent and the methods concerning their use in research
Tangible Technologies for Childhood Education: A Systematic Review [31]	2019	not specifically focused on ER	childhood education	Find out which are the most used tangible technologies used in childhood education and for which purpose
Towards a definition of educational robotics: a classification of tools, experiences and assessments [1]	2019	ER is the sum of several factors: Robots allowing a construction/deconstruction and programming activity; teachers/experts facilitating the activity; methodologies enabling students to explore the subject, the environment, the content of the activity, and their personal skills and knowledge	K12	identify experiences, tools, and evaluation methods, to draw a classification of experiences that could eventually lead to a definition of ER
A Systematic Review on Exploring the Potential of Educational robotics in Mathematics Education [8]	2020	not specified	K12 and University	review the empirical evidence on the application of robotics in mathematics education
Educational robotics for children with neurodevelopmental disorders: A systematic review [32]	2020	ER is considered a part of social robotics, namely the use of robots for the education of children with special needs. In other words, any kind of robot interacting with children for educational purposes. In this context, children are meant to give instructions to the robot (or to create a program for it) to accomplish a specific task. This can be realized in many different ways, but the important thing is that the pupil should be engaged in an activity aimed at planning, designing, or implementing an algorithm to control the robot's behavior.	children with neurodevelopmental disorders	Investigate whether there is sound evidence that activities with robots improve the abilities and performances of children with special needs.
Educational robotics for STEM: A review of technologies and some educational considerations [33]	2020	defined as a cross-thematic playful learning tool that, in most cases, combines mechanical constructions with simple, physical tangible or graphical programming environments that enable users to transform their constructions into intelligent objects interacting with the environment and responding to external stimulations	not specified	review the available educational robotics technologies that have appeared in the international literature aimed to support both researchers and STEM educators
Empowering technology and engineering for STEM education through programming robots: a systematic literature review [34]	2020	programmable toys and robotics construction kits	0–8 years old	synthesize findings from studies that provided programming experiences through robotics for children and reveal the possible contributions of robotics programming for the integration of technology and engineering in STEM education.
Coding and educational robotics and their relationship with computational and creative thinking. A compressive review [35]	2020	not specified	not specified	comment definitions and measurements of computational and creative thinking and maker movement
Educational Robotics: Platforms, Competitions and Expected Learning Outcomes [36]	2020	''research field aimed at promoting active, engaging learning through the artifacts students create and the phenomena they simulate''	not specified	attempt to update the definition and re reapproach the field of ER
Educational robotics and STEAM in early childhood education [15]	2021	Educational robotics manage to combine learning through play, so education is easily transformed into a fun procedure, as it is widely known that learning is done easier, faster, and more effectively when is combined with play.	4–5 years old	Understand whether preschoolers can operate, program, and control an educational robot and whether ER supports STEAM education

TABLE II
(CONTINUED)

Title	Year	Definition of the scope of the field of ER	Age range	Aim of the study
Educational robots Improve K-12 Students' Computational Thinking and STEM Attitudes: Systematic Review [7]	2021	not specified	K12	evaluate the effectiveness of educational robots in promoting the development of students' computational thinking, collaboration, critical thinking, spatial ability and other abilities; evaluate to what extent educational robots' outcomes are moderated by gender, teaching experiment period, and grade level
Educational robotics in Primary Education: A Systematic Literature Review [16]	2021	An interdisciplinary learning environment based on the use of robots and electronic accessories for the purpose of improving learning outcomes and developing students' skills/abilities	primary education	review literature about ER focusing on the learning environment, the area of knowledge/course subjects, the pedagogical framework, the learning activities, the robotic equipment, the research methodology, and the main findings.
Simulators in educational robotics: A Review [37]	2021	not specified	not specified	review of the characteristics of educational robotics simulators with Graphical User Interfaces (GUIs).
Computer vision meets educational robotics [38]	2021	not specified	K12	investigate the current status and benefits of the use of computer vision in educational robotics
Systematic Review on Which Analytics and Learning Methodologies Are Applied in Primary and Secondary Education in the Learning of robotics Sensors [39]	2021	Constructing a robot is considered an integral part of the learning process, where the creativity and enthusiasm of students are stimulated through an open-ended and problem-solving process in the real world	primary and secondary school	Analyze the pedagogical-methodological interventions which lead to a better understanding and knowledge in the use of sensors in educational robotics; identify the Learning Analytics processes that analyze and reflect on students' behavior in their learning of concepts and skills of sensors in educational robotics
Robotics as a didactic tool for students with autism spectrum disorders: a systematic review [40]	2021	social robots	not specified (ASD patients	deepen the field of science that combines social robotics and learning difficulties, specifically autism spectrum disorders, from an educational perspective.
Systematic Literature Review of Realistic Simulators Applied in Educational robotics Context [41]	2021	not specified	not specified	Explore the capabilities of the simulators which are used in the context of educational robotics
Educational Robotics and Tangible Devices for Promoting Computational Thinking [42]	2021	child-centered use of technology in school contexts seeks to provide children with the opportunity to research, discover, and apply knowledge in an authentic context	not declared, but resulting in a selection of devices suitable for students aged 4–11	Analyze Tangible Programming Language solutions to report technical issues and how researchers see their use in educational environments
Fostering STEAM through challenge-based learning, robotics, and physical devices: A systematic mapping literature review [43]	2021	not specified, general STEAM education considered	not specified, general STEAM education considered	understand the landscape of the application of robotics and mechatronics in STEAM Education and how active methodologies are applied in this sense
ICT Enabled TVET Education: A Systematic Literature Review [44]	2021	focuses only on studies reporting ICT in TVET education, not just robotics in education or educational robotics	not specified, general TVET programs (formal and nonformal education)	explore ICT-based technology innovations, research, and applications used in Technical and Vocational Education and Training (TVET) training cycle system components/functional areas
Preschool children, robots, and computational thinking: A systematic review [45]	2021	not specified	early childhood (not further specified in the text)	Find out which robots are used and how can they be classified; what are the characteristics of the activities that aim to stimulate the development of computational thinking and how to evaluate CT
Robotics in Education: A Smart and Innovative Approach to the Challenges of the 21st Century [46]	2021	RiE	K12	highlight the key points that emerge from the recent enhancements in Robotics in Education
Understanding the role of single-board computers in engineering and computer science education: A systematic literature review [47]	2021	robotics is not the focus	not specified	understand the main features and main outcomes of using single board computers in the educational areas of engineering and computer science

TABLE II
(CONTINUED)

Title	Year	Definition of the scope of the field of ER	Age range	Aim of the study
Exploring the Features of Educational Robotics and STEM Research in Primary Education: A Systematic Literature Review [17]	2022	ER activities based on the fact that knowledge is an experience constructed by interaction with the environment and when real-world content is used, learning is more effective	primary education (up to 12 years)	explore the intersection between ER and STEM education to find out the most commonly used study design, sample characteristics, and equipment
A systematic review of educational robotics studies for the period 2010–2021 [48]	2022	not specified	not specified	review the theses on educational robotics applications produced in Turkey to provide recommendation to stakeholders
Educational robotics studies in Italian scientific journals: A systematic review [49]	2022	not specified	not specified	review of the research literature published in Italy to find out the goals, practices, and benefits of using robots in the educational context
A scoping review on the relationship between robotics in educational contexts and e-health [50]	2022	not specified	not specified	review complementary themes in educational research about ER: (1) teaching and computational thinking, (2) training in the health sector, and (3) education and special needs.
Robotics and Education: A Systematic Review [51]	2022	Educational robotics is part of the area of robotics called social robotics.	not specified	find out characteristics about the experiences like the aim of the studies and the profile of participants
Educational interventions with robots for students on the autism spectrum. A systematic review [52]	2022	social robotics from an educational point of view.	not specified	review the use of robotics as a tool in educational intervention with people with ASD, to understand how many articles deal with the theme, which are the objectives, profile of the participants and equipment

TABLE III
COLLECTED APPLICATIONS OF ER

Title	Year	Methodology	Age range	Number of participants	Nationality	Aim of the study	Type of Robotic kit	Main Findings
What pupils can learn from working with robotic direct manipulation environments [55].	2011	A six-session, 2-hour intervention was conducted based on a Direct Manipulation Environment (DME). Each session was recorded, with a webcam focusing on students working in pairs, their interactions, construction and testing activities, and conversations with the researcher. The student's programming tasks were also recorded with a camera, while screen shots were taken continuously. Students' comprehension was explored in relation to function, system, control, and sense-reason-action loop.	11–12 years old (Final year elementary school students)	Not mentioned (A class of last year elementary school students- six pairs were singled out for investigation).	Netherlands	The study aimed to investigate the impact of working with robotics on the technological literacy of young students.	Lego Mindstorms NXT robots.	Cognitive and conceptual analysis of robotics showed that participants were able to gradually develop more advanced conceptual perspectives. The study supports that pupils developed a functional technological literacy as the practical activities to compare robots, to reconstruct a robot, to analyse a problem, to design, build, and program a robot helped them to become more competent users of this technology.
Robotics teaching in primary school education by project based learning for supporting science and technology courses [56].	2011	A project-based robotics study was conducted with students divided into 4 groups of different levels. Participants were directed to complete each step of the robot design and development process in 12 weekly meetings. The evaluation strategy concerns the completion of weekly reports and a midterm examination covering the calculation of resistance, circuit information and basic information about robots, as these were the main objectives for the first eight weeks.	10–15 years old (Primary school)	16 students	Istanbul	The aim of the reported study was to develop a robotics laboratory course to support the learning of science in the electrical circuit and to investigate its impact on primary school students.	Electronics elements and material to develop a robot.	According to the results of the midterm exams, group members who were 7th or 8th grades demonstrated high scores in calculation of resistance, while 6th grade students improved their performance in circuit design. At the end of the lesson, the students realized the necessity and technological importance of the kits they used to build robots and showed interest in electronic circuits and other components, so the incompletion tasks included only failed work and the average completion rate of all groups was is high (68%).

TABLE III
(CONTINUED)

Title	Year	Methodology	Age range	Number of participants	Nationality	Aim of the study	Type of Robotic kit	Main Findings
Spatial ability learning through educational robotics [57].	2015	Students participated in practical cooperative experiences in the form of a Mathematical problem-solving workshop of 10 sessions conducted within 10 weeks. Student learning was recorded for each session in work files. Additional images and videos recorded the procedures and physical constructions created by the students, while the teacher also made continuous observations of the students during the sessions. Participants were assigned into control and intervention groups, where students in the control group did not attend the robotics class but went to the Mathematics workshop that was scheduled at that time.	12 years old (sixth grader)	21 students	Spain	The study aims to analyze the use of ER to develop spatial abilities in 12 years old elementary students.	The materials used in the sessions consisted of three different Fischertechnik 3 sets: Universal 3; ROBO LT Beginner Lab; and Oeco Tech.	The results of the study showed that the students who joined the robotics course demonstrated a significantly greater increase in their spatial abilities compared to students in the control group. The study also revealed that students 'overall performance depended on the specific nature of each sub-test, demonstrating the importance of an informed and well-thought-out selection of instruments that can be used to assess students' spatial abilities.
The Game of Science An Experiment in Synthetic Roboethology with Primary School Children [58].	2016	Robotic activities were developed to provide a playful way of using already built and programmed robots to support elementary school students in acquiring exploratory skills. The activities were piloted in a one-month program in which a cycle of such laboratory activities was carried out. The students were not familiar with the functions of the robot as the main purpose was to describe and explain its behavior. Students' verbal interactions during a series of sessions were recorded and used by researchers who adopted an ethnographic approach to assess students' scientific and abstract reasoning skills.	Age is not specified (Second graders).	Not mentioned (A class of second-graders).	Italy	The study aims to enhance primary school children's ability to conduct cross-disciplinary scientific inquiry.	LEGO Mindstorms robots.	The study concluded that students demonstrated scientific research skills during the pilot, such as making observations, coming up with explanatory hypotheses and identifying alternative explanatory hypotheses, thus supporting the idea that such activities can be useful for introducing scientific research to primary school children.
Educational Robotics intervention on Executive Functions in preschool children: A pilot study [12].	2017	This study concerns a game of intensive robotic activities that took place twice a week. Scaffolding activities initially aimed to acquaint students with the robot and the narrative context of the activities and in the next stage the children to give a series of instructions for movement or rotation based on different conditions. Activities focused mainly on response inhibition, interference control, working memory and cognitive flexibility. Students' neuropsychological assessments were performed in three stages at regular intervals of 6 weeks: before the control period, pre-training, and post-training.	5–6 years old (pre-school students)	12 pupils	Italy	The aim of this study was to evaluate the short-term effects in Preschool children of intensive ER training on Executive Functions.	A bee-shaped robot, called Bee- Bot. The design of Bee-Bot is adapted to be child user. The toy has a black/yellow bee shape, is easy to use and handle.	The study findings suggest that ER is suitable for the progressively improvement of skills in planning and controlling complex tasks in early childhood, enhancing the development of executive functions.
Robotics and computational	2018	The study involved four primary school teachers, (Years 1–6) from four schools in Australia. Each teacher was	Not mentioned (Primary school	Not mentioned (four schools)	Australia	This paper reports on a research study that examined	LEGO WeDo 2.0 robotics	Overall, the results showed that the activities boosted teachers' confidence and

TABLE III
(CONTINUED)

Title	Year	Methodology	Age range	Number of participants	Nationality	Aim of the study	Type of Robotic kit	Main Findings
thinking in primary school [59].		provided with robot kits for six weeks along with software and teacher guides but they were not instructed on how to use them in their classrooms. The research study used a multi-case study design and includes data from teacher questionnaires and interviews about: their experience in teaching and robotics; their initial ideas for robotics and computational thinking; how they and their students perceived the activities; what was their contribution; their perceptions of the learning tools used; their assessments of student learning; useful pedagogical strategies; and whether their knowledge and confidence in teaching robotics had increased.	grades 1–6).			how Australian primary school teachers integrated robotics and coding in their classrooms and the perceived impact this had on students' computational thinking skills.	kits along with software and teacher guides.	knowledge to ER. However, further support is needed for teachers to realize how ER can specifically advance the concepts, practices, and perspectives of computational thinking. Despite the technical challenges and lack of knowledge about coding, computational thinking and robotics implementation at schools, teachers reported that the activities benefited students since they focused on the technical details of robot programming and solved problems using computational concepts such as sequences and loops. Students also developed a computational perspective and solved problems they identified with the construction and program of their robots.
Exploring the Effect of a Robotics Laboratory on Computational Thinking Skills in Primary School Children Using the Bebras Tasks [60].	2018	A project-based learning laboratory of robotics was conducted in four 2-hour sessions, where primary school students were supported by third-grade students from a computer science high school. Trainees and peer-coaches were introduced to the technology by exploring the visual programming environment as well as the hardware components kit. The students then experimented with building new robots and programming them to solve STEM challenges. To assess the impact of ER, a control group was designed where its members followed the regular school curriculum. After the workshop, Bebras tests and questionnaires were assigned to participants and teachers to assess students' academic performance and average performance in STEM, computational thinking, satisfaction and experience.	8–10 (primary school 3rd and 4th graders)	Not specified (2 classes from the same primary school).	Italy	This paper presents preliminary findings from a project-based learning laboratory of robotics aimed at stimulating computational thinking processes in primary school students.	Robotics tools such as the Lego Education WeDo 2.0 kit.	Overall, the results showed that robotic kit programming can positively impact students' acquisition of computational thinking skills. Specifically, the children who participated in the robotics laboratories performed higher in a set of "real life" problem-solving tasks than those who followed the regular school curriculum. In addition, students' computing skills developed more in robotic programming activities than in context implying everyday reasoning. The students in the intervention group appreciated the laboratory activities as an attractive way of exploring and learning academic subjects. On the other hand, the students in the comparison group found the tasks more difficult to complete.
Adaptive Robotic Tutors that Support Self-Regulated Learning: A Longer-Term Investigation with Primary	2018	Students interacted individually with a fully autonomous robot that supports the learner throughout the learning process, and provides a summary at the end of each session. The study designed a control condition where the robotic teacher provides only domain support, while in the intervention group the robot teacher provides further SRL Scaffolding support	10–12 years old	24 primary school students	United Kingdom	This paper explores how personalized tutoring by a robot achieved using an open learner model (OLM) promotes SRL processes and how this can impact learning	The robotic tutor was an Aldebaran Robotics NAO torso. The robotic assistant incorporat	Results demonstrated that the autonomous robotic tutor personalizes and adaptively scaffolds SRL behavior since students who were provided with this condition achieved higher indications of SRL behavior than the control group.

TABLE III
(CONTINUED)

Title	**Year**	**Methodology**	**Age range**	**Number of particip ants**	**Natio nality**	**Aim of the study**	**Type of Robotic kit**	**Main Findings**
School Children [61].		based on the student's skill levels, learning performance and rules for appropriate SRL behavior. In both cases, the robot acted autonomously as a social robotic tutor in a geography task where it was possible to demonstrate SRL skills and processes. Prior to the study, students were asked to complete a domain assessment test and a SRL self-report questionnaire. Before and after each session, students filled out questionnaires describing the level of skills they had developed. Moreover, after completing the 4 sessions, the students completed a domain test and a questionnaire with questions about his skills in SRL.				and SRL skills compared to personalized domain support alone.	es a multiplatf orm applicatio n that can be deployed in iOS, Android, and desktop environm ents (Window s, GNU/Lin ux, and MacOS).	
A robotic assistant to support the social and cognitive developme nt of children from low-income families [62].	2018	To evaluate how children from middle and low-income families perceive the robotic technology, all of the students participated in the study interacted with the robotic assistant and a mobile app (Android). The robot used is part of the of the project "Sciences in classroom from children" that aims to encourage pupils the study of science, technology and robotics though workshops in the learning topics of robotics, electricity, magnetism, digital electronic, and ecology. To assess the robot's feasibility, the researchers used a layer service module that allows Cronbach's value to be determined as well as data mining procedures to be performed. Children's perception was measured using a survey with a five-point Likert scale that received a Cronbach value of 0.87.	8–10 years old	68 children from middle and low-income families.	Ecuado r	The study aimed at evaluating how children from low-income families perceive the use of a robotic assistant.	The robot used is part of the of the project "Sciences in classroom from children". In terms of experime ntation, there were experime ntal kits for electrical circuits, renewable energies, and robotics. Participan ts interacted with the robot and a mobile app (Android) .	The study revealed that educational robotic assistant was positively perceived by children who participated in the study. In addition, the analysis revealed important student requests for improving the robotic assistant, including the development of more educational content with regard to the subjects taught at school, a computer vision-based interactive module (pattern and gesture recognition) and an intelligent module to generate personalized work plans.
Educationa l Robotics in Primary School: Measuring the Developme nt of Computati onal Thinking Skills with the Bebras Tasks [63].	2019	In the context of ER, a basic robotics laboratory was designed with the aim of enhancing the computational thinking of the participants. The laboratories took place for a total of 4 sessions, each of them consisted of a two-hours meeting. The first meeting was introductory to the software and hardware applied while in next sessions students constructed and programmed their own robots to perform basic actions. To evaluate the use of robotics laboratory, researchers of that study adopted a quasi-experimental post-test-only	8 to 10 years old (two third-grade classrooms and one fourth-grade classroom).	83 students (51 students participat ing in the robotics laboratori es and 32 students participat ing to the control group).	Italy	The primary research questions of the study were to investigate whether a robotics laboratory can impact the development of CT skills in children aged 8 to 10 and whether this impact differs between third and fourth-grade students.	Lego® Education WeDo 2.0 kit.	The results revealed students who received the robotics laboratory intervention performed better in acquiring computational thinking skills than those assigned to the control group. In addition, within the intervention groups, the students attending in the third grade exceeded the performance of their older classmates in the fourth grade.

TABLE III
(CONTINUED)

Title	Year	Methodology	Age range	Number of participants	Nationality	Aim of the study	Type of Robotic kit	Main Findings
		design, by providing a set of Bebras assignments to students participated in laboratory interventions as well as to those who attended the regular school curriculum.						
Robotics as a Tool to Enhance Technological Thinking in Early Childhood [64].	2020	The study presents a compulsory early robotics program for primary and kindergarten education. The program was implemented for two years and in the second year received official approval to conduct research. The research study involved kindergartens and first graders who attended robotics and technology classes throughout the school year, one hour per week for kindergartens and 2 hours per week for primary school students. Following the program, the children participants were assessed via quantitative and qualitative analysis on their knowledge of basic robotics, sensors and programming. Moreover, the study explored children's understanding and technological thinking as well as their attitudes on robotics and technology education.	Not specified (kindergartens and first graders).	197 children	Israel	The study aims to present the use of robotics as a tool to develop essential twenty-first-century skills and to increase children's self-confidence in the use of technology.	The type of the used robot is not mentioned.	By applying quantitative and qualitative analysis methods, the study revealed that kindergarten and elementary school children received robotics and technology education as fun and showed their desire to pursue such programs in the future. In addition, participation in the program improved children's self-efficacy and confidence in their ability to invent new robots and other technological devices.
Educational Robotics at Primary School: Comparison of Two Research Studies [65].	2021	-Taiwan: Students participated in a robotics course, where they had to control a robot by completing tasks. The researchers aimed at a heterogeneous grouping of students' overall learning performance to support collaboration and expression. To evaluate students' learning performance, personal effort, teacher influence, lesson quality, personal innovation and behavioral intent, the researchers assigned respective questionnaires to students to complete before and after the intervention. In addition, the study included the observations of the teachers made during the lessons. -Slovakia: Students were involved in the construction and programming 45-minute activities for 12 weeks. The researchers adapted the Lego WeDo activities by developing their own curriculum. The study evaluated the curriculum developed in terms of construction and motivation, worksheet work, guidance and collaboration. The researchers applied qualitative assessment methods and collected various types of data, including model photos, video recordings of student work, field notes from the classroom, and interviews with teachers.	-Taiwan: not specified (1st to 4th grade). -Slovakia: approximately 8–10 years old (2nd to 4th grade).	-Taiwan: 1st grade 114 pupils, 2nd grade 113 pupils, 3rd grade 135 pupils, 4th grade 133 pupils. -Slovakia: not mentioned.	Taiwan and Slovakia	The paper presents two studies aimed at introducing robotics education in primary schools with the aim of improving students' programming and problem-solving skills. The first study was conducted in Taiwan and the second study in Slovakia.	-Taiwan: Dash Robot and Path app. -Slovakia: LEGO WeDo kit	The conclusions in which both studies agree are that educational robotics brings elements into learning that are motivating to pupils, they stimulate their interest in discovering and exploring, and develop various skills such as communication, collaboration, fine motor skills, etc. In an interactive way, they also demonstrate the results of the pupils' programs. Pupils find this attractive which can lead to a better understanding of the program.

TABLE IV
COLLECTED FRAMEWORKS FOR ER

Title	Year	Methodology	Age range	Number of participants	Nationality	Aim of the study	Type of Robotic kit	Main Findings
An Approach to Rescue Robot Workshops for Kindergarten and Primary School Children [66].	2013	The workshops took place in 2010 and 2011 and each workshop lasted 3 weeks (one 2.5 hours activity per week) in which the students experienced a flow of activities, produced a rescue robot while playing with it and operated it. The participating students worked with undergraduate and postgraduate students trained in technology and information in education as well as with their parents who always accompanied them. However, students constructed the rescue robots themselves, as this was the main goal of the projects. A questionnaire survey on parents views was conducted in the middle and at the end of the workshop.	4–8 years old (Most of the participants were in kindergarten or the early grades of primary school).	Not mentioned	Japan	Aiming to foster pupils attitudes on science and technology learning as well as manufacturing, researchers of the study developed and tested via rescue robot workshops a curriculum for kindergarten and primary education.	The rescue robot was made up of individually prepared robot parts from an educational material manufacturer used in the Technology Education classes in the junior high school. A crawling rescue robot was used in 2010, and a walking rescue robot was used in 2011.	The survey results revealed that most of the parents participants liked the manufacturing (80%) and found their children to enjoy it (90%), while all were positive towards the workshop (100%). These results show that the main feature of this workshop gained the understanding of parents. The researchers of the study found that all the children who participated were able to create and complete their own robot and that the idea of rescue encouraged the children's feelings towards others. They claim that a curriculum that includes construction experience and understanding of structures using robots can enhance the development of various skills in kindergarten and elementary school children, such as collaboration skills and skills that will help them relate well to others.
AERobot: An affordable one-robot-per-student system for early robotics education [67].	2015	"AERobot" was developed as an open source system for early robotics education that allows each student to interact with their own robot, while still including a rich sensor suite. The system was tested with a pilot course developed using AERobot and attended by students enrolled in grades 5–8 in an elementary school in the United States (USA). Participating students had little or no previous experience in programming and robotics and came from low-income families. The pilot course was conducted for three sessions where the third session was held with self-selected students who participated due to personal interest. Fifth and sixth graders participated in all sessions.	5th to 8th grade	41 students (17 rising 5th and 6th graders; 14 rising 7th and 8th graders)	United States (USA)	This study aimed to develop an affordable, simple and easy-to-use robot for robotics and introductory programming in primary and secondary education. In particular, the design goals of the robot developed were to be very low cost, to support a wide variety of behaviours and to be robust and easy to use.	"AERobot" was developed as an open source rich sensor system for early robotics education. AERobot Open-source package Minibloq was modified to support AERobot-specific hardware and functions.	The findings of the study suggest that participants showed overall satisfaction and enjoyment of the course and increased their understanding and interest in both programming and robotics. Regarding the improvement of the system, teacher and students agreed that the most important factor is that the robot engine needs better calibration, however this was expected by the researchers.

TABLE IV
(CONTINUED)

Title	Year	Methodology	Age range	Number of participants	Nationality	Aim of the study	Type of Robotic kit	Main Findings
Artificial intelligence and computer science in education: From kindergarten to university [68].	2016	An integral part of the framework are the principles of constructionism as well as the application of various learning methods and techniques such as inquiry, problem-based and collaborative learning. The researchers developed and evaluated the modules of their framework for each level of education. With regard to primary education and kindergarten, the researchers developed a module that aims to teach graphs and data structures, sorting algorithms, and problem-solving by searching in a playful way using different learning tools and robotic platforms. All participants were provided with introductory activities. The module was implemented and evaluated in the form of a project day in a kindergarten where students participated in several introductory workshops on the principles of AI, computer science, and robotics. Moreover, during the activities, the children accompanied students of pedagogical schools, who hosted and explained the activities to them. Qualitative and quantitative empirical research methods applied for the evaluation of the modules including video data, pictures, observations during the day of the project, semi-structured interviews with pedagogical school students and students' drawings after the project. The middle school module was implemented in the form of a summer research week (three days, six hours a day) conducted in a robotics laboratory. By the end of the module, participants will have programmed a robot with all the functions pre-implemented as well as they will have evaluated, compared and documented different search strategies. The evaluation techniques used are various including: group discussion to detect students' prior knowledge; domain post-questionnaire; observations; pictures and videos of the project; students' feedback and self-evaluation post-questionnaire; and students' programming solutions, documentation and presentation.	Kindergarten: aged 5 years in average. Middle school: aged 12 years in average.	24 kindergarten children and 24 middle school students	Austria	This paper introduces a novel artificial intelligence (AI) education concept that can be used for various levels of education, including education from kindergarten to university. Aiming at fostering AI literacy, the authors/researchers developed a framework that includes modules that address fundamental AI/computer science topics.	Kindergarten: In this context we used different learning tools (robotics platforms like Bee-Bots [44], LEGO Mindstorms NXT [45] and Cubelets [46] robotics kits, but also non-robotics material like standard LEGO bricks). Middle School: Learning tools used in this module are the educational robotics platform LEGO Mindstorms NXT as well as paper-and-pencil and computer science unplugged exercises.	Due to the relatively small sample of participants evaluation results only provide preliminary insights and first hints. Kindergarten: Children explored the activities in a joyful way, understood the simplified concepts of artificial intelligence and carried out most of the activities successfully. Middle school: students were enthusiastic and liked the activities. They found the activities challenging but not too difficult and gained a basic understanding of graphs, trees, data structures, and search strategies. However, students had some problems understanding the connection between the basic concepts of AI and their application. Therefore, the researchers of the study claim that the proposed middle-school module should be implemented by adapting its duration, the student's programmatic effort and the number of topics addressed to the activities to the skills and needs of students of this age.

TABLE IV
(CONTINUED)

Title	**Year**	**Methodology**	**Age range**	**Number of participants**	**Nationality**	**Aim of the study**	**Type of Robotic kit**	**Main Findings**
Making Robot Challenges with Virtual Robots [69].	2017	As an example of the process to design and run a challenge, one of the challenges was used in a robotics competition conducted in 2016. The competition simulates an unexpected problem occurring at a remote location such as a space station or planetary habitat, where a robotic solution must be quickly developed and deployed, using only existing resources. Throughout the morning students, without the help of teachers, have to program and problem solve to complete as many tasks as possible using the hardware robots or the virtual ones. The afternoon is reserved for the actual competition when students take turns completing tasks with the hardware robots on the competition boards to earn points. Teachers had access to older competition challenges and they could repeat the challenge in their classroom, giving students the opportunity to test their problem-solving skills on a copy of the competition.	Not specified (K-12 schools and community colleges)	100 teams from various K-12 schools and community colleges	United States (US)	This paper presents a methodology for creating challenge problems using a simulation environment for a hardware robot-based programming competition.	The Linkbots are small, educational modular robots designed for ease-of-use and the basis for this competition. Controlling the Linkbots is done through Ch, a C/C++ interpreter. RoboSim is a simulator developed to seamlessly integrate into the control methodology of the Linkbot modular robot.	The results showed that RoboSim simulator allows more efficient and quick design as well as allows students' preparation for the challenges. Moreover, the students' responses to the competition and RoboSim were positive as the addition of RoboSim for testing their code in virtual robots allowed students to quickly improve their solutions before applying them to the physical robots.
Design of IoT tangibles for primary schools: A case study [70].	2017	In this study was conducted a 2-h workshop focused on fabricating IoT tangibles related to socio-emotional learning which fits the curriculum, does not require Fablab facilities, and does not require teachers to have computing skills and IoT interests. The project was voluntarily attended by primary school students with no experience whatsoever in interaction design or programming. Participants were provided with a scaffolding intervention in which they passed through the stages of introduction, ideation, conceptualization, prototyping and programming. During the study were collected data based on the designers' views, students' recorded videos and interviews conducted during the workshop. Moreover, at the start and towards the end of the project children were asked about their experience, their perception of interaction design and programming, and what tangible they liked best. A post-workshop survey was conducted asking children to indicate whether they would repeat or recommend the design experience to others, as well as feel free to add other thoughts about the experience.	10–11 years old	21 children	Italy	This framework narrates a lab experience in a primary school class to explore how to bring IoT tangible design to children of this age and their teachers.	Scaffolding intervention: Paper-based generative toolkits; an adapted version of Tiles cards; primitive cards; construction kits (e.g., Lego blocks), physical objects (e.g., soft balls), programmable sensors and actuators. SAM labs sensors and actuators were chosen so as to maintain costs low and to be easy-to-use.	Overall, the results of the study revealed that the students had no experience in interaction design or programming and demonstrated positive outcomes in the activities. Students reported that they easily or manageable perceive programming and experts confirmed their views. Finally, correspondingly positive results were reported for the participation of students.

TABLE IV
(CONTINUED)

Title	**Year**	**Methodology**	**Age range**	**Number of participants**	**Nationality**	**Aim of the study**	**Type of Robotic kit**	**Main Findings**
Minding the Gap. Proposing a Teacher Learning-Training Framework for the Integration of Robotics in Primary Schools [71].	2017	Considering the Activity Theory, the authors identified constructionism and project based learning (PBL) as conceptual foundations for teachers who aim to teach ICT and want to support their students in developing computational thinking skills. The authors demonstrated a generic teacher-training framework that consists of two dimensions including a guiding checklist for best practises and an activity plan template. The best practice checklist was proposed aims to assists teachers in defining the context, learning objectives, resources and tools and sustainability of a robotics education activity as well as in evaluating student outcomes. In turn, the activity template presents prerequisites for teachers, aims, learning outcomes and indicative equipment/methodologies for primary education robotic activities, which are based on important principles of constructionism.	X	X	Italy	The authors aimed to develop a tool for mediating between the professional qualities of teachers and the effective deployment of robotics in primary schools. The proposed tool aimed to be an editable by teachers framework for activities, goals, learning outcomes and indicative complementary material.	X	Invariably designed in young but evolving flourishing research scenarios it is understood that as the framework model is adopted it is prone to be modified in context of use. This implies that the presented framework is in all facts a works in progress initiative. Undeniably its strength lies in the recursive dialogues that can potentially take place when after being deployed within targeted teacher circles the same teachers will be able report 'back to base' with new ideas and customizations.
Nurture interest-driven creators in programmable robotics education: an empirical investigation in primary school settings [72].	2019	In this study was designed a ER course to be examined how students pass through the phases of triggering, immersing and extending interest. The course is designed with 10 units of teaching materials which students needs approximately 10-12 hours to complete. Each unit demonstrates a robotics problem-solving task in which students are strongly encouraged to discuss with their group members. Teachers introduce to students the core concepts aimed to be taught before each unit. Students were provided with a questionnaire to complete before completing the course. The questionnaire was constructed based on a Likert scale of 3-5 points with the aim of capturing students' interest (triggering, immersing and extending), creative efficacy, meaningfulness, impact, robotics education and collaborative learning. The study's results are based on Confirmatory Factor Analysis (CFA) and Structural Equation Modelling (SEM).	Not specified (5 Graders).	801 primary school students (Five graders from 31 primary schools. On average, 26 students from each participating school joined.)	China	This study aims to empirically investigate how students' interest in programmable robotics develops and how it contributes to robotics creation. Inspired by the Interest-Driven Creator (IDC) theory, the researchers of that study have formulated questions that can confirm the validity of the interesting loop about robotics education.	In class, students had full access to the mBot robots, computers, and tablets.	Confirmatory factor analysis suggested a good fit of the study variables in terms of convergent and discriminant validity. Structural equation modelling indicated significant and positive paths from triggering interest to immersing interest, and from immersing interest to extending interest, suggesting the valid theoretical proposition of interest loop of IDC theory. In addition, immersing interest is positively related to robotics creation, which in turn increases the chance of extending interest. Our findings suggested the importance of raising students' interest in robotics learning such that young students can become life-long interest-driven creators. Implications of the study were discussed at the end of the paper.

TABLE IV
(CONTINUED)

Title	Year	Methodology	Age range	Number of participants	Nationality	Aim of the study	Type of Robotic kit	Main Findings
Identification of the students learning process during education robotics activities [73].	2020	Students participated in a one-session robotics course based on constructionism approach and problem-solving learning methods. The participants worked in groups and were introduced to the course as well as the actuators and ultrasonic sensor of the robot before conducting the lesson. Utilizing visual programming and the robot's sensor the mission of the student teams was to instruct the robot to stop at a given distance from the wall. The robot software has been modified so that it can monitor students' solutions and store them on an SD card installed in the robot. Students' effort was recorded in log files which were collected and analysed by the researchers of the study. By applying machine learning techniques, the researchers of the study demonstrated an approach for detecting students problem-solving pathways and analysing how students utilize sensors during an education robotics activity.	14 Italian primary and lower/higher secondary schools. First: Average Age (AA)= 17.29, Second: AA=11.45, Third: AA=10.08, Fourth: AA=11.70, Fifth: AA=11.63, Sixth: AA=15.92, Seventh: AA=12.00, Eighth: AA=12.43, Ninth: AA=9.63, Tenth: AA=12.54, Eleventh: AA=10.21, Twelfth: AA= not specified, Thirteenth: AA=11.87, Fourteenth: AA=10.24	353 students from 14 primary and lower/higher secondary schools. First: 62 students, Second: 22 students, Third: 24, Fourth: 21,Fifth: 19, Sixth: 25, Seventh: 24, Eighth: 23, Ninth: 30, Tenth: 26, Eleventh: 19, Twelfth: 9, Thirteenth: 23, Fourteenth: 26	Italy	This study aims to identify the learning process of young students while engaging in ER activities.	Lego Mindstorms EV3 robot and a modified version of the Lego Mindstorms EV3 Education Software.	The log files showed that groups of students demonstrated ten different problem-solving paths. Further analysis revealed that students followed two main programming approaches: a step-by-step process with the application of small adjustments, which was selected by most participants; and an approach with highly modifications to their programming blocks.
Assessing the Current Level of the Computational Thinking Within the Primary and Lower Secondary School Students using Educational Robotics Tasks [5].	2020	By reviewing previous literature, researchers of this study designed a set of 16 tasks as a tool to access students CT-Skills based on a complex problem solution, replication of a route and the creation of the student's own route. The developed tool was gradually tested on students during nonformal education activities for the analysis of prerequisite CT skills. The participating students were familiar with ER and computing, but had never tried the introduced educational robots in formal education. The tasks were based on a complex problem solution, replication of a route and the creation of the student's own route in a cross domain activity context. Due to the complex problem-solving tasks, older pupils were assigned to complete the entire set of tasks while younger pupils could choose a shortened version of 12 items. Tasks involving coding activities were pre-programmed and students had to fill in empty lines of code with their answers. The researchers personally supervise the students during the test, observe their approach to the project and qualitatively evaluate their performance.	8–13 years old	90 students	Czech Republic	The aim of this research was to develop a set of tasks assessing prerequisite Computational Thinking (CT) skills within primary and lower secondary school students using an educational robotics as a supporting tool.	The educational robots Ozobot EVO and BIT were used for the creation tasks and subsequent testing.	It was shown that activities with less than seven number of empty lines had a higher success rate than those with more empty cells. The researchers argued that working with a larger number of empty code cells offers more possible solutions and supports creativity. Tasks with more than ten empty code cells were considered to belong to the same level of complexity as students showed similar success rates in such exercises. They also claimed that the types of errors presented in students' tasks can lead to a fundamental knowledge of the requirements for conducting STEM and robotics teaching. The analysis of tasks revealed that students showed a higher success rate in creative tasks and their performance seemed to decrease depending on the difficulty of the tasks. Finally, despite the fact that students with a lack of previous experience showed lower performance, they were found to be naturally adapted to the use of new unfamiliar to them technology.

REFERENCES

[1] D. Scaradozzi, L. Screpanti, and L. Cesaretti, "Towards a definition of educational robotics: A classification of tools, experiences and assessments," in *Smart Learning with Educational Robotics*. Berlin, Germany: Springer, 2019, pp. 63–92.

[2] F. B. V. Benitti, "Exploring the educational potential of robotics in schools: A systematic review," *Comput. Educ.*, vol. 58, no. 3, pp. 978–988, 2012, doi: 10.1016/j.compedu.2011.10.006.

[3] L. Xia and B. Zhong, "A systematic review on teaching and learning robotics content knowledge in K-12," *Comput. Educ.*, vol. 127, pp. 267–282, 2018.

[4] L. P. E. Toh, A. Causo, P.-W. Tzuo, I.-M. Chen, and S. H. Yeo, "A review on the use of robots in education and young children," *J. Educ. Technol. Soc.*, vol. 19, no. 2, pp. 148–163, 2016.

[5] L. Bryndová and P. Mališů, "Assessing the current level of the computational thinking within the primary and lower secondary school students using educational robotics tasks," in *Proc. ACM Int. Conf. Proc. Ser.*, 2020, pp. 239–243, doi: 10.1145/3416797.3416819.

[6] A. Ioannou and E. Makridou, "Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work," *Educ. Inf. Technol.*, vol. 23, pp. 2531–2544, 2018.

[7] Y. Zhang, R. Luo, Y. Zhu, and Y. Yin, "Educational robots improve K-12 students' computational thinking and STEM attitudes: Systematic review," *J. Educ. Comput. Res.*, vol. 59, no. 7, pp. 1450–1481, 2021.

[8] B. Zhong and L. Xia, "A systematic review on exploring the potential of educational robotics in mathematics education," *Int. J. Sci. Math. Educ.*, vol. 18, pp. 79–101, 2020.

[9] J. López-Belmonte, A. Segura-Robles, A. J. Moreno-Guerrero, and M. E. Parra-González, "Robotics in education: A scientific mapping of the literature in Web of Science," *Electronics*, vol. 10, no. 3, 2021, Art. no. 291, doi: 10.3390/electronics10030291.

[10] L. Daniela and M. D. Lytras, "Educational robotics for inclusive education," *Technol., Knowl. Learn.*, vol. 24, pp. 219–225, 2019.

[11] L. Daniela and R. Strods, "Educational robotics for reducing early school leaving from the perspective of sustainable education," in *Smart Learning With Educational Robotics: Using Robots to Scaffold Learning Outcomes*, L. Daniela, Ed. Berlin, Germany: Springer, 2019, pp. 43–61.

[12] M. C. Di Lieto et al., "Educational robotics intervention on executive functions in preschool children: A pilot study," *Comput. Hum. Behav.*, vol. 71, pp. 16–23, 2017, doi: 10.1016/j.chb.2017.01.018.

[13] E. Tzagkaraki, S. Papadakis, and M. Kalogiannakis, "Exploring the use of educational robotics in primary school and its possible place in the curricula," in *Studies in Computational Intelligence*, vol. 982. Berlin, Germany: Springer, 2021, pp. 216–229, doi: 10.1007/978-3-030-77022-8_19.

[14] B. Arfé, T. Vardanega, and L. Ronconi, "The effects of coding on children's planning and inhibition skills," *Comput. Educ.*, vol. 148, 2020, Art. no. 103807, doi: 10.1016/j.compedu.2020.103807.

[15] D. Chaldi and G. Mantzanidou, "Educational robotics and STEAM in early childhood education," *Adv. Mobile Learn. Educ. Res.*, vol. 1, no. 2, pp. 72–81, 2021, doi: 10.25082/AMLER.2021.02.003.

[16] I. Kyriazopoulos, G. Koutromanos, A. Voudouri, and A. Galani, "Educational robotics in primary education: A systematic literature review," in *Research Anthology on Computational Thinking, Programming, and Robotics in the Classroom*, I. M. Association, Ed. Hershey, PA, USA: IGI Global, 2022, pp. 782–806.

[17] S. Tselegkaridis and T. Sapounidis, "Exploring the features of educational robotics and STEM research in primary education: A systematic literature review," *Educ. Sci.*, vol. 12, no. 5, 2022, Art. no. 305, doi: 10.3390/educsci12050305.

[18] Y. W. Cheng, P. C. Sun, and N. S. Chen, "The essential applications of educational robot: Requirement analysis from the perspectives of experts, researchers and instructors," *Comput. Educ.*, vol. 126, pp. 399–416, 2018, doi: 10.1016/j.compedu.2018.07.020.

[19] J. Gallagher, N. Preston, R. Holt, M. Mon-Williams, M. Levesley, and A. Weightman, "Assessment of upper limb movement with an autonomous robotic device in a school environment for children with Cerebral Palsy," in *Proc. IEEE Int. Conf. Rehabil. Robot.*, 2015, pp. 770–774, doi: 10.1109/ICORR.2015.7281295.

[20] O. Mubin, C. J. Stevens, S. Shahid, A. A. Mahmud, and J.-J. Dong, "A review of the applicability of robots in education," *J. Technol. Educ. Learn.*, vol. 1, pp. 1–7, 2013.

[21] D. Alimisis, "Educational robotics: Open questions and new challenges," *Themes Sci. Technol. Educ.*, vol. 6, no. 1, pp. 63–71, 2013.

[22] M. E. Karim, S. Lemaignan, and F. Mondada, "A review: Can robots reshape K-12 STEM education?," in *Proc. IEEE Int. Workshop Adv. Robot. Social Impacts*, 2015, pp. 1–8, doi: 10.1109/ARSO.2015.7428217.

[23] S. Kubilinskienė, I. Žilinskienė, V. Dagienė, and V. Sinkevičius, "Applying robotics in school education: A systematic review," *Baltic J. Mod. Comput.*, vol. 5, no. 1, pp. 50–69, 2017, doi: 10.22364/bjmc.2017.5.1.04.

[24] S. A. Ajwad, N. Asim, R. U. Islam, and J. Iqbal, "Role and review of educational robotic platforms in preparing engineers for industry," *Maejo Int. J. Sci. Technol.*, vol. 11, no. 1, pp. 17–34, 2017.

[25] N. Spolaôr and F. B. V Benitti, "Robotics applications grounded in learning theories on tertiary education: A systematic review," *Comput. Educ.*, vol. 112, pp. 97–107, 2017, doi: 10.1016/j.compedu.2017.05.001.

[26] T. Sapounidis and S. Demetriadis, "Educational robots driven by tangible programming languages: A review on the field," in *Educational Robotics in the Makers Era*. Berlin, Germany: Springer, 2017, pp. 205–214.

[27] S. E. Jung and E. Won, "Systematic review of research trends in robotics education for young children," *Sustainability*, vol. 10, no. 4, 2018, Art. no. 905, doi: 10.3390/su10040905.

[28] F. Jamet, O. Masson, B. Jacquet, J.-L. Stilgenbauer, and J. Baratgin, "Learning by teaching with humanoid robot: A new powerful experimental tool to improve children's learning ability," *J. Robot.*, vol. 2018, 2018, Article no. 4578762, doi: 10.1155/2018/4578762.

[29] S. Anwar, N. A. Bascou, M. Menekse, and A. Kardgar, "A systematic review of studies on educational robotics," *J. Pre-College Eng. Educ. Res.*, vol. 9, no. 2. pp. 19–42, 2019, doi: 10.7771/2157-9288.1223.

[30] B. K. M. K. Pedersen, J. C. Larsen, and J. Nielsen, "The effect of commercially available educational robotics: A systematic review," in *Proc. Int. Conf. Robot. Educ.*, 2019, pp. 14–27, doi: 10.1007/978-3-030-26945-6_2.

[31] C. S. González-González, M. D. Guzmán-Franco, and A. Infante-Moro, "Tangible technologies for childhood education: A systematic review," *Sustainability*, vol. 11, no. 10, 2019, Art. no. 2910, doi: 10.3390/su11102910.

[32] M. Pivetti, S. Di Battista, F. Agatolio, B. Simaku, M. Moro, and E. Menegatti, "Educational robotics for children with neurodevelopmental disorders: A systematic review," *Heliyon*, vol. 6, no. 10, 2020, Art. no. e05160, doi: 10.1016/j.heliyon.2020.e05160.

[33] T. Sapounidis and D. Alimisis, "Educational robotics for STEM: A review of technologies and some educational considerations," in *Science and Mathematics Education for 21st Century Citizens: Challenges and Ways Forward*. Hauppauge, NY, USA: Nova Sci. Publishers, 2020, pp. 167–190.

[34] M. Çetin and H. Ö. Demircan, "Empowering technology and engineering for STEM education through programming robots: A systematic literature review," *Early Child Develop. Care*, vol. 190, no. 9, pp. 1323–1335, 2020, doi: 10.1080/03004430.2018.1534844.

[35] R. A. Martínez, J. Lavonen, and M. Zapata-Ros, "Coding and educational robotics and their relationship with computational and creative thinking. A compressive review," *Revista de Educación a Distancia*, vol. 20, no. 63, pp. 1–21, 2020, doi: 10.6018/red.413021.

[36] S. Evripidou, K. Georgiou, L. Doitsidis, A. A. Amanatiadis, Z. Zinonos, and S. A. Chatzichristofis, "Educational robotics: Platforms, competitions and expected learning outcomes," *IEEE Access*, vol. 8, pp. 219534–219562, 2020, doi: 10.1109/ACCESS.2020.3042555.

[37] S. Tselegkaridis and T. Sapounidis, "Simulators in educational robotics: A review," *Educ. Sci.*, vol. 11, no. 1, 2021, Art. no. 11, doi: 10.3390/educsci11010011.

[38] A. Sophokleous, P. Christodoulou, L. Doitsidis, and S. A. Chatzichristofis, "Computer vision meets educational robotics," *Electronics*, vol. 10, no. 6, 2021, Art. no. 730, doi: 10.3390/electronics10060730.

[39] D. Amo, P. Fox, D. Fonseca, and C. Poyatos, "Systematic review on which analytics and learning methodologies are applied in primary and secondary education in the learning of robotics sensors," *Sensors*, vol. 21, no. 1, 2021, Art. no. 153, doi: 10.3390/s21010153.

[40] I. A. Perez, A. H. Burgos, and I. R. Rodríguez, "Robotics as a didactic tool for students with autism spectrum disorders: A systematic review," *Revista científica electrónica de Educación y Comunicación en la Sociedad del Conocimiento*, vol. 21, no. 1, pp. 51–82, 2021, doi: 10.30827/eticanet.v21i1.18137.

[41] C. Camargo, J. Gonçalves, M. Conde, F. J. Rodríguez-Sedano, P. Costa, and F. J. García-Peñalvo, "Systematic literature review of realistic simulators applied in educational robotics context," *Sensors*, vol. 21, no. 12, 2021, Art. no. 4031, doi: 10.3390/s21124031.

[42] M. G. Funk, J. M. Cascalho, A. I. Santos, and A. B. Mendes, "Educational robotics and tangible devices for promoting computational thinking," *Front. Robot. AI*, vol. 8, 2021, Art. no. 713416, doi: 10.3389/frobt.2021.713416.

[43] M. Conde, F. J. Rodríguez-Sedano, C. Fernández-Llamas, J. Gonçalves, J. Lima, and F. J. García-Peñalvo, "Fostering STEAM through challenge-based learning, robotics, and physical devices: A systematic mapping literature review," *Comput. Appl. Eng. Educ.*, vol. 29, no. 1, pp. 46–65, 2021, doi: 10.1002/cae.22354.

[44] R. H. Hassan, M. T. Hassan, S. Naseer, Z. Khan, and M. Jeon, "ICT enabled TVET education: A systematic literature review," *IEEE Access*, vol. 9, pp. 81624–81650, 2021, doi: 10.1109/ACCESS.2021.3085910.

[45] E. Bakala, A. Gerosa, J. P. Hourcade, and G. Tejera, "Preschool children, robots, and computational thinking: A systematic review," *Int. J. Child-Comput. Interact.*, vol. 29, 2021, Art. no. 100337, doi: 10.1016/j.ijcci.2021.100337.

[46] L. Screpanti, B. Miotti, and A. Monteriù, "Robotics in education: A smart and innovative approach to the challenges of the 21st century," in *Makers At School, Educational Robotics and Innovative Learning Environments*, vol. 240. Cham, Switzerland: Springer, 2021, pp. 17–26.

[47] J. Ariza and H. Baez, "Understanding the role of single-board computers in engineering and computer science education: A systematic literature review," *Comput. Appl. Eng. Educ.*, vol. 30, no. 1, pp. 304–329, 2022, doi: 10.1002/cae.22439.

[48] H. Gunes and S. Kucuk, "A systematic review of educational robotics studies for the period 2010–2021," *Rev. Educ.*, vol. 10, no. 3, 2022, Art. no. e3381, doi: 10.1002/rev3.3381.

[49] G. Bonaiuti, L. Campitiello, S. Di Tore, and A. Marras, "Educational robotics studies in Italian scientific journals: A systematic review," *Front. Educ.*, vol. 7, 2022, Art. no. 1005669, doi: 10.3389/feduc.2022.1005669.

[50] K. Sannicandro, A. De Santis, C. Bellini, and T. Minerva, "A scoping review on the relationship between robotics in educational contexts and e-health," *Front. Educ.*, vol. 7, pp. 1–17, 2022, doi: 10.3389/feduc.2022.955572.

[51] I. Arocena, A. Huegun-Burgos, and I. Rekalde-Rodriguez, "Robotics and education: A systematic review," *TEM J.*, vol. 11, no. 1, pp. 379–387, 2022, doi: 10.18421/TEM111-48.

[52] I. A. Pérez, A. H. Burgos, and I. R. Rodríguez, "Educational interventions with robots for students on the autism spectrum : A systematic review," *RELATEC Rev. Latinoam. Tecnol. Educ.*, vol. 21, no. 2, pp. 27–43, 2022, doi: 10.17398/1695-288X.21.2.27.

[53] M. D. J. Peters, C. M. Godfrey, P. McInerney, B. C. Soares, H. Khalil, and H. Parker, *The Joanna Briggs Institute Reviewers' Manual 2015: Methodology for JBI Scoping Reviews*. Adelaide, SA, Australia: Joanne Briggs Inst., 2015, pp. 1–24.

[54] A. C. Tricco et al., "PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation," *Ann. Intern. Med.*, vol. 169, no. 7, pp. 467–473, 2018, doi: 10.7326/M18-0850.

[55] L. Slangen, H. Van Keulen, and K. Gravemeijer, "What pupils can learn from working with robotic direct manipulation environments," *Int. J. Technol. Des. Educ.*, vol. 21, no. 4, pp. 449–469, 2011, doi: 10.1007/s10798-010-9130-8.

[56] D. Karahoca, A. Karahoca, and H. Uzunboylu, "Robotics teaching in primary school education by project based learning for supporting science and technology courses," *Procedia Comput. Sci.*, vol. 3, pp. 1425–1431, 2011, doi: 10.1016/j.procs.2011.01.025.

[57] C. Julià and J. Ò. Antolí, "Spatial ability learning through educational robotics," *Int. J. Technol. Des. Educ.*, vol. 26, no. 2, pp. 185–203, 2016, doi: 10.1007/s10798-015-9307-2.

[58] E. Datteri and L. Zecca, "The game of science: An experiment in synthetic roboethology with primary school children," *IEEE Robot. Autom. Mag.*, vol. 23, no. 2, pp. 24–29, Jun. 2016, doi: 10.1109/MRA.2016.2533038.

[59] C. Chalmers, "Robotics and computational thinking in primary school," *Int. J. Child-Comput. Interact.*, vol. 17, pp. 93–100, 2018, doi: 10.1016/j.ijcci.2018.06.005.

[60] G. Chiazzese, M. Arrigo, A. Chifari, V. Lonati, and C. Tosto, "Exploring the effect of a robotics laboratory on computational thinking skills in primary school children using the Bebras tasks," in *Proc. ACM Int. Conf. Proc. Ser.*, 2018, pp. 27–30, doi: 10.1145/3284179.3284186.

[61] A. Jones and G. Castellano, "Adaptive robotic tutors that support self-regulated learning: A longer-term investigation with primary school children," *Int. J. Social Robot.*, vol. 10, no. 3, pp. 357–370, 2018, doi: 10.1007/s12369-017-0458-z.

[62] A. Parra-Astudillo et al., "A robotic assistant to support the social and cognitive development of children from low-income families," in *Proc. IEEE Biennial Congr. Argentina*, 2019, pp. 1–6, doi: 10.1109/ARGENCON.2018.8646155.

[63] G. Chiazzese, M. Arrigo, A. Chifari, V. Lonati, and C. Tosto, "Educational robotics in primary school: Measuring the development of computational thinking skills with the Bebras tasks," *Informatics*, vol. 6, no. 4, 2019, Art. no. 43, doi: 10.3390/informatics6040043.

[64] R. Zviel-Girshin, A. Luria, and C. Shaham, "Robotics as a tool to enhance technological thinking in early childhood," *J. Sci. Educ. Technol.*, vol. 29, no. 2, pp. 294–302, 2020, doi: 10.1007/s10956-020-09815-x.

[65] P.-J. Wu, F.-Y. Chiu, K. Mayerova, and Z. Kubincova, "Educational robotics at primary school: Comparison of two research studies," in *Proc. 17th Int. Conf. Inf. Technol. Higher Educ. Training*, 2018, pp. 1–5, doi: 10.1109/ITHET.2018.8424621.

[66] K. Kawada, M. Nagamatsu, and T. Yamamoto, "An approach to rescue robotworkshops for kindergarten and primary school children," *J. Robot. Mechatron.*, vol. 25, no. 3, pp. 521–528, 2013, doi: 10.20965/jrm.2013.p0521.

[67] M. Rubenstein, B. Cimino, R. Nagpal, and J. Werfel, "AERobot: An affordable one-robot-per-student system for early robotics education," in *Proc. IEEE Int. Conf. Robot. Autom.*, 2015, pp. 6107–6113, doi: 10.1109/ICRA.2015.7140056.

[68] M. Kandlhofer, G. Steinbauer, S. Hirschmugl-Gaisch, and P. Huber, "Artificial intelligence and computer science in education: From kindergarten to university," in *Proc. IEEE Front. Educ. Conf.*, 2016, pp. 1–9, doi: 10.1109/FIE.2016.7757570.

[69] K. J. Gucwa and H. H. Cheng, "Making robot challenges with virtual robots," in *Proc. ACM SIGCSE Tech. Symp. Comput. Sci.*, 2017, pp. 273–278, doi: 10.1145/3017680.3017700.

[70] R. Gennari, A. Melonio, M. Rizvi, and A. Bonani, "Design of IoT tangibles for primary schools: A case study," in *Proc. ACM Int. Conf. Proc. Ser.*, 2017, pp. 1–6, doi: 10.1145/3125571.3125591.

[71] P. Camilleri, "Minding the gap. Proposing a teacher learning-training framework for the integration of robotics in primary schools," *Inform. Educ.*, vol. 16, no. 2, pp. 165–179, 2017, doi: 10.15388/infedu.2017.09.

[72] S. C. Kong and Y. Q. Wang, "Nurture interest-driven creators in programmable robotics education: An empirical investigation in primary school settings," *Res. Pract. Technol. Enhanced Learn.*, vol. 14, 2019, doi: 10.1186/s41039-019-0116-1.

[73] D. Scaradozzi, L. Cesaretti, L. Screpanti, and E. Mangina, "Identification of the students learning process during education robotics activities," *Front. Robot. AI*, vol. 7, 2020, Art no. 21, doi: 10.3389/frobt.2020.00021.

[74] J. M. N. Piedade, "Pre-service and in-service teachers' interest, knowledge, and self-confidence in using educational robotics in learning activities," *Educ. Formação*, vol. 6, no. 1, 2020, Art. no. e3345, doi: 10.25053/redufor.v6i1.3345.

Eleni Mangina (Senior Member, IEEE) was born in Athens, Greece, in 1973. She received the M.Sc. degree in artificial intelligence from the Department of Artificial Intelligence, the University of Edinburgh, Edinburgh, U.K. in 1998, the M.Sc. degree in agricultural science from the Agricultural University of Athens, Athens, in 1996, and the Ph.D. degree (working on agent-based applications for intelligent data interpretation) from the Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, U.K., in 2001.

In 2002, she joined the School of Computer Science, University College Dublin, Dublin, Ireland. She has an extensive experience for the last 20 years in national, EU, and internationally funded projects and authored more than 200 peer-reviewed articles in national and international peer-reviewed workshops and conferences and international journals, including in IEEE and ACM. She is currently a Professor at the School of Computer Science, University College Dublin, and the Vice Principal (International) for the College of Science. Her lab operates at the intersection between applied artificial intelligence (VR/AR, data analytics, UAVs, and information systems) and portfolio development within interdisciplinary applications (i.e., energy sector and educational systems with XR).

Dr. Mangina contributes to IEEE Standards as an Executive Editor for the publications of the IEEE Global Initiative on XR Ethics. She is currently the Chair of the Athena SWAN Bronze Award application for the School of Computer Science.

Georgia Psyrra received the Bachelor's degree in early childhood education and teaching from the University of Thessaly, Volos, Greece, in 2014, and realized importance of ICT applications in education, the Bachelor's degree in computer science and engineering from the Department of Computer Science and Telecommunication, Technological Institute of Thessaly, Larissa, Greece, in 2020, and the M.Sc. Research degree in computer science from the University College Dublin (UCD), Dublin, Ireland, in 2022.

In 2020, after the completion of dissertation, she started her internship with the Department of Computer Science, University College Dublin, through the Erasmus+ program. Her master's dissertation was focused on the development of a movie recommendation system in data analysis. She conducted research for the AHA (ADHD Augmented) project, which aimed to leverage augmented reality technology tools for children and adolescents with attention deficit hyperactivity disorder during her internship.

Ms. Psyrra was the recipient of the scholarship from the ARETE Project to carry out her master's degree by research titled "Educational data analytics and learning objects for immersive educational systems."

Laura Screpanti (Member, IEEE) received the B.S. degree in biomedical engineering, the M.Sc. degree in electronic engineering, and the Ph.D. degree in information engineering (working on modeling learning from students engaged in activities of educational robotics) from Università Politecnica delle Marche, Ancona, Italy, in 2011, 2014, and 2020, respectively.

From 2015 to 2016, she was a Research Assistant at the Department of Biomedical Sciences and Public Health for the development of a mechatronic infrastructure gathering biometric signals from SCUBA divers during their underwater activity. She has been an Adjunct Professor of systems modeling and identification and a Teacher of real-time systems with the "Fondazione ITS Nuove Tecnologie per il Made in Italy." She is an expert on educational robotics and innovative STEAM methodologies to fight against gender stereotypes for the National Institute for Documentation, Innovation and Educational Research (INDIRE). She is currently a Postdoctoral Researcher with the Department of Engineering Information, Università Politecnica delle Marche, Ancona, Italy. Her research interests include educational robotics, systems modeling and identification, research methodologies, and techniques.

Dr. Screpanti is a Member of the IEEE Education Society and the IEEE Robotics and Automation Society.

David Scaradozzi (Member, IEEE) received the M.Eng. degree in electronics, with a specialization in control and automation, and the Ph.D. degree in artificial intelligent systems from Università Politecnica delle Marche (UNIVPM), Ancona, Italy, in 2001 and 2005, respectively.

His research interests include control and optimization of dynamical systems, robotics and automation (motion and interaction control problems in distributed agents and rapid prototyping and mechatronics), educational robotics, with special interests devoted to all the aspects regarding the study and development of new robotic tools and lesson plans for teaching e-STrEM subjects, in formal and nonformal education, and underwater robotics and marine technologies, focusing on tools for 3-D documentation of sea operative surveys for marine protected areas and archaeological sites. He is a member of the Interuniversity Center of Integrated Systems for the Marine Environment, Genova, Italy, where he cooperates with the Italian Navy and NATO. He is the author of about 115 publications in refereed international journals, books, and conferences. He is currently an Assistant Professor with the Department of Information Engineering, UNIVPM.