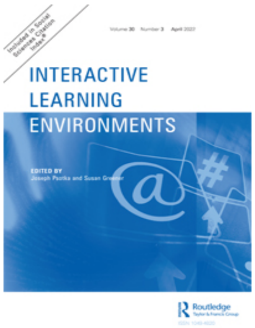

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REVIEW ARTICLE

A systematic review study on educational robotics and robots

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ABSTRACT
This study, which systematically examines educational robotics and robots (ERR), has two purposes. (1) Classifying the research on the ERR to identify research trends and gaps, (2) Summarizing the experimental findings related to ERR and to interpret them according to the claims in the literature. A mixed method combining systematic mapping and systematic review were used in the study. Ninety-three articles published in Social Sciences Citation Index (SSCI) indexed journals and meeting the specified criteria were analyzed using a systematic mapping process. The results showed that 40 out of 93 articles did not include any learning theory. Thirty-two experimental studies were analyzed within the scope of the systematic review. The empirical findings supporting some of the claims about ERR are summarized and the research gaps in the claims that need to be supported by theoretical and pedagogical approaches are revealed.

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Educational robotics; educational robots; systematic mapping; systematic review

1. Introduction

Educational robotics and robots (ERR) are recognized as innovative learning tools that can transform education and support students in many learning contexts (Evripidou et al., 2020). ERR is seen as a core part of Science, Technology, Engineering, Mathematics (STEM) (Sophokleous et al., 2021) and an interdisciplinary educational tool (Kubilinskiene et al., 2017). ERR is often used to introduce students to engineering concepts (Okita, 2014) and encourage interdisciplinary practices and career development of students. At the same time, ERR has increasingly been used in K-12 and university contexts as applications and tools driven by Artificial Intelligence technologies (Chen et al., 2020a). ERR provides a popular educational context for integrating AI applications in education (Chen et al., 2020b), and new opportunities for applying it to teaching and learning design (Hwang et al., 2020). For these reasons, studies about ERR are steadily increasing and diversifying. Recently, the studies have spread from kindergartens to universities. Also, this spread was impacted by economic and technological factors, including nurturing a workforce with computer skills (Chen et al., 2017).

The use of ERR in educational environments has many potentials. Educational robotics supports the development of many skills such as problem-solving, self-efficacy, computational thinking, creativity, motivation, and cooperation (Evripidou et al., 2020). The integration of educational robotics in learning and teaching processes is important in supporting the education of students who do not show immediate interest in academic disciplines related to science or technology (Anwar et al., 2019). In addition, educational robots are used in many areas such as developing social psychological skills and foreign language learning for students with learning disabilities. Robots offer possibilities such as manipulating objects and using gestures to support language teaching (van den Berghe

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This article has been corrected with minor changes. These changes do not impact the academic content of the article.

et al., 2019). However, there are concerns in the literature regarding the potential of ERR. Alimisis (2009) reported that there is a criticism of the lack of quantitative research on how robotics can increase students' learning achievements. In addition, it is suggested that questions about the important uses and purposes of ERR in education should be answered (Cheng et al., 2018). It is also stated that the role of robotics in the development of computational thinking is not clear to associate theoretical assumptions with practice (Ioannou & Makridu, 2018).

These criticisms, expressed especially for ERR, are made for the field of instructional technology. However, two issues are raised in criticisms related to the studies in the field of instructional technologies. One of them is that most of the studies in the field of instructional technologies are not based on learning theories, and the second is that the reason for the difference in comparative studies is focused on the method or intervention process rather than discussing the theoretical mechanism (Hew et al., 2019). For this reason, the emphasis continues to be given to the educational media, possibly due to this problem. While these discussions continue in the context of education, most learners do not use technology to achieve education and production (Gallardo-Echenique et al., 2015; Luckin et al., 2009; Usluel & Atal, 2013). Most students use ICT during their spare times rather than for learning purposes (Hinostroza et al., 2014; Thomson, 2013; Wang et al., 2014; Yuen et al., 2016). On the other hand, the daily use of technology may be limited in tasks that require synthesis and critical evaluation skills (Lai & Hong, 2015). However, making learners productive rather than content consumers are being explored in the world. Educational robotics and robots (ERR) have been suggested as a solution for the productive and creative use of technology.

From these points of view, this review will try to make a comparison of the extent to which the claims about the potential of ERR are supported by experimental studies by investigating the uses of ERR and the theoretical frameworks on which the studies are based. Therefore, the intent of the study is to keep a projection for future research rather than providing evidence of the validity of the claims.

1.1. Educational robotics and robots

In this study, ERR is discussed under two headings as educational robotics and educational robots. The main reason why it is addressed under two headings can be explained with the metaphors of "black box" and "white box" (Kynigos, 2004). Accordingly, robots are first pre-fabricated and programmed, then presented to the user as a tool and therefore referred to as a black box; on the other hand robotics allows the user to create and programme it, so it is called as the white box (Alimisis, 2009). Educational robots are defined as programmed machines to fulfil different tasks, designed with various parts, working with operators or autonomously (American Robotic Institute, 1979). Educational robots can be in the form of humans, animals, or vehicles in different shapes and sizes. Educational robotics is introduced as a teaching/learning tool that encourages students to operate their models using graphical or textual programming languages and enables them to use problem-solving skills in this process (Alimisis, 2009). Accordingly, in educational robotics activities, there is a process in which the robot is constructed and programmed according to a model designed by the student using various kits such as blocks, motor, sensor, and microcontroller. The difference between these concepts is that the robot is presented to the student pre-programmed, while the robotics allows the student to programme it. Hence, programmed or programmable equipment can be selected and used for different educational purposes.

In this respect, there are many claims about why robotics and robots should be used in educational settings. Accordingly, the claims about ERR were discussed under four headings:

Claim 1. Educational robotics promote higher-order thinking skills

Studies have included claims that educational robotics can benefit from developing high-order thinking skills such as deep thinking, individual and collaborative problem-solving. In this context, robotics offers a concrete way for the learners to understand abstract concepts (Chambers et al., 2008; Hadjiachilleos et al., 2013; Kazakoff & Bers, 2014). Educational robotics can support collaborative problem-solving processes (Taylor & Baek, 2018), computational thinking (Chen et al., 2017;

Sarıtepeci & Durak, 2017) and higher-order thinking skills (Atmatzidou et al., 2018). Besides, educational robotics activities provide a context suitable for problem-solving and deep learning (Gomoll et al., 2017), analogical reasoning, and the practicing of modeling activities (Cuperman & Verner, 2019).

Claim 2. Educational robots improve social skills of the students

There are claims that the interaction of students' with the educational robot contributes to the development of social skills. Robots could be considered social actors (Chin et al., 2014). Learners can interact socially with a humanoid robot, social robot, or robot companion (Crompton et al., 2018; Fridin & Belokopytov, 2014; Han et al., 2015). A robot partner under the individual's control can provide self-confidence in social interaction (Mazzoni & Benvenuti, 2015) and expand their interactions with the society (Hsiao et al., 2015).

Claim 3. Educational robotics and robots support the affective characteristics of students

There are claims that educational robotics and robots contribute to development of affective characteristics. Regarding educational robotics, Mitnik et al. (2009a), referring to Piaget (1981), stated that a physical element in the learning environment rather than a virtual object brings about stronger affective bonds. Besides, it was claimed that educational robotics can increase students' interest in STEM (Gomoll et al., 2016; Jaipal-Jamani & Angeli, 2017) and their STEM career (Dolenc et al., 2016). Also, learners like the physical character more and show a deeper engagement with robots (Chang et al., 2010a). Individuals who feel anxious about their performance while learning to speak English can talk with robot partners (Iio et al., 2019). Studies also showed that it can increase students' interest and motivation in English (Lee et al., 2011) and reading (Hsiao et al., 2015).

Claim 4. Educational robotics and robots contribute to learning performance

Another claim in the literature about educational robotics and robots is that they improve students' learning performance in some subject areas. It was claimed that educational robotics improves learning in STEM disciplines (Kim et al., 2015; Sullivan & Bers, 2018; Taylor & Baek, 2018); science literacy (Sullivan, 2008), logic and mathematics (Kazakoff & Bers, 2014). Educational robots improve learning and assist students (Wei & Hung, 2011). Besides, there are claims that educational robots can be beneficial in foreign language teaching (Chang et al., 2010b; Chen et al., 2011; Wang et al., 2013; Wu et al., 2015).

It is noteworthy that the claims about robotics and robots sometimes intersect and, in some cases, are different. For example, the discussions about promoting high-order thinking skills are put forward for robotics, while developing social skills are emphasized for robots. On the contrary, the discussions about supporting the development of affective characteristics and contributing to learning performance are put forward for both.

1.2. Previous review studies

With the diversification and increase of ERR researches, review researches with different focuses have started to be carried out. There are reviews on the potential of ERR in STEM education (Çetin & Demirci, 2020; Pedersen et al., 2021; Sapounidis & Alimisis, 2020). In addition, reviews were conducted on the role of artificial intelligence and robotics in education in the learning process (Cox, 2021). Several SLR studies have been focused on specific usage of ERR (Anwar et al., 2019; Benitti, 2012; Spolaôr & Benitti, 2017; Toh et al., 2016; van de Berghe et al., 2019; Xia & Zhong, 2018). Table 1 represents these studies chronologically with explanations about their purpose and scope.

Although previous SLR studies contribute to the understanding of ERR, some limitations have to be reported. First, previous review studies have focused on one of roles of ERR, such as robotics (i.e. Anwar et al., 2019; Benitti, 2012; Xia & Zhong, 2018) or robots (van den Berghe et al., 2019). However, as stated in the introduction, even using it for different educational purposes, it is necessary to approach robots and robotics holistically. A previous review study has been carried out considering two ways of use, robot, and robotics (Toh et al., 2016), the included research study is limited only to the kindergarten. In this context, there is a gap in the literature regarding a comprehensive

Table 1. Previous SLR studies on ERR.

Reference	Purpose of the studies	Robotic/ Robot	Study Group	f*
Benitti (2012)	Reviewing the effectiveness of using robotics as a tool in teaching a subject.	Robotics	K12	10
Toh et al. (2016)	The ways in which robots can help young children develop skills have been reviewed.	Robotics & Robots	Kindergarten	27
Spoalor and Benitti (2017)	Review of topics and learning theories taught through educational robotics at the university.	Robotics	Tertiary institution	15
Xia and Zhong (2018)	Review of intervention approaches that are effective in learning and teaching robotics content knowledge.	Robotics	K12	22
Anwar et al. (2019)	To classify the relevant studies of educational robotics according to their contribution to increasing students' capacities by considering psychological, organizational and cultural mechanisms.	Robotics	K12	147
van den Berghe et al. (2019)	Review of current possibilities and limitations of using Robot-Assisted Language Learning (RALL) for first and second language learning	Robots	No age restriction	32

systematic mapping (SM) study that deals with robotics and robots. Regarding systematic literature review (SLR) studies, Benitti (2012) examined ten studies on the use of robotics as a tool in teaching a topic. In this study, only experimental studies were focused and the findings on the effectiveness of robotics were summarized. In addition, no analysis was made according to the theoretical frameworks on which the studies are based. Xia and Zhong (2018), reviewed 22 experimental studies on robotics content knowledge. This study has limitations such as the selection of studies with the snowballing approach and including only experimental studies. Accordingly, it is seen that there is a need for a more comprehensive review study with the potential of ERR.

1.3. Purpose of the study

There are two purposes of this study. The first one is to identify trends and gaps in the literature by comprehensively approaching how robots and robotics are used in education, classifying research, and describing their distribution. The second aim is to summarize the experimental findings related to ERR and to interpret them according to the claims in the literature. Thus, future research trends can be identified to enlighten claims that need empirical support, and conclusions can be drawn regarding considerations for researchers and practitioners.

Accordingly, four research questions were formulated for the review. Among these questions, the first three questions will be examined with SM, and the fourth question with the SLR approach. The research questions are listed below:

(RQ1): What are the ERR research trends in terms of their research issues and demographics?

(RQ2): Which theoretical models are the studies based on?

(RQ3): How and in what ways are ERR used in the research?

(RQ4): What are the findings of experimental findings on ERR?

2. Method

SM and SLR, also known as secondary research, are approaches that research, review, classify, or synthesize previous studies. While SM studies are about the classification of articles related to the research field, the SLR approaches are about the review process by focusing on specific research questions. A SM study is an inventory of articles matched with a classification in the subject area (Wieringa et al., 2005). On the other hand, SLR studies synthesize the studies' results to be relevant to the research questions (Budgen et al., 2018). A mixed method combining systematic mapping and systematic review was used in the study.

2.1. Research process

The research was conducted in the Social Science Citation Index (SSCI) to access the high-quality papers. In the SSCI index, 3400 journals were scanned in 58 different social sciences disciplines; 24 quality and four impact criteria were used to select these journals (Clarivate Analytics, 2020). A topic search was used to retrieve the records. Two keyword groups were created: (a) related to the learning and teaching process (b) related to robots and robotics. The OR operator was used among the synonyms and close meanings of these words; the AND operator for associating the two groups of keywords. As this study will try to classify the studies related to ERR, papers reporting the sections about the methods and findings were included in the review. In this respect, considering the possibility of not reaching the sections in the book chapters and conference publications, the search string was formulated to return records in article type. As a result, the following research string was used:

> ((TS = ((teach * OR learn * OR education * OR instruction OR course OR student OR child *) AND (robot * OR Lego))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) Timespan: All years. Indexes: SSCI.

2.2. Study selection

In the study selection process, the following Inclusion Criteria (IC) and Exclusion Criteria (EC) were specified to assess retrieved records:

> IC1: Articles in which robots and robotics are used in the learning and teaching process at all educational levels (kindergarten, primary school, secondary school, high school, higher education).
>
> IC2: Articles in Education & Educational Studies Category
>
> IC3: Articles with full-text access and published in English
>
> EC1: Articles that are not in the Education & Educational Studies category
>
> EC2: Articles without full-text access
>
> EC3: Articles that do not use ERR as a learning or teaching tool.
>
> EC5: Articles dealing only with virtual or remote laboratories
>
> EC6: Articles intended for review of the literature.

After determining the search string and the inclusion/exclusion criteria, the search was carried out in April 2019. The steps followed in the selection of the study were presented in Figure 1.

As seen in Figure 1, 1768 records were accessed as a result of the first search. Among these records, 1570 records were excluded because they are not classified under Education & Educational Studies (EC1). The remaining 198 articles were examined in detail by two researchers; 12 were excluded according to EC2 as they did not have full-text access. Seventy-seven of these articles were not included according to EC3, as it was established that ERR was not used in the learning and teaching processes. Six articles were not included because they focused on remote or virtual laboratories (EC4). Ten articles were excluded according to EC5, as the literature review addressed systematic review, needs analysis, curriculum framework proposal, or pedagogical applications. As a result of the search process, 93 articles were obtained. Two researchers participated in selecting the studies and carried out the selection process independently to control the threat of bias during the selection of the studies. The studies selected under the third researcher's control were examined, and the articles to be reviewed were determined.

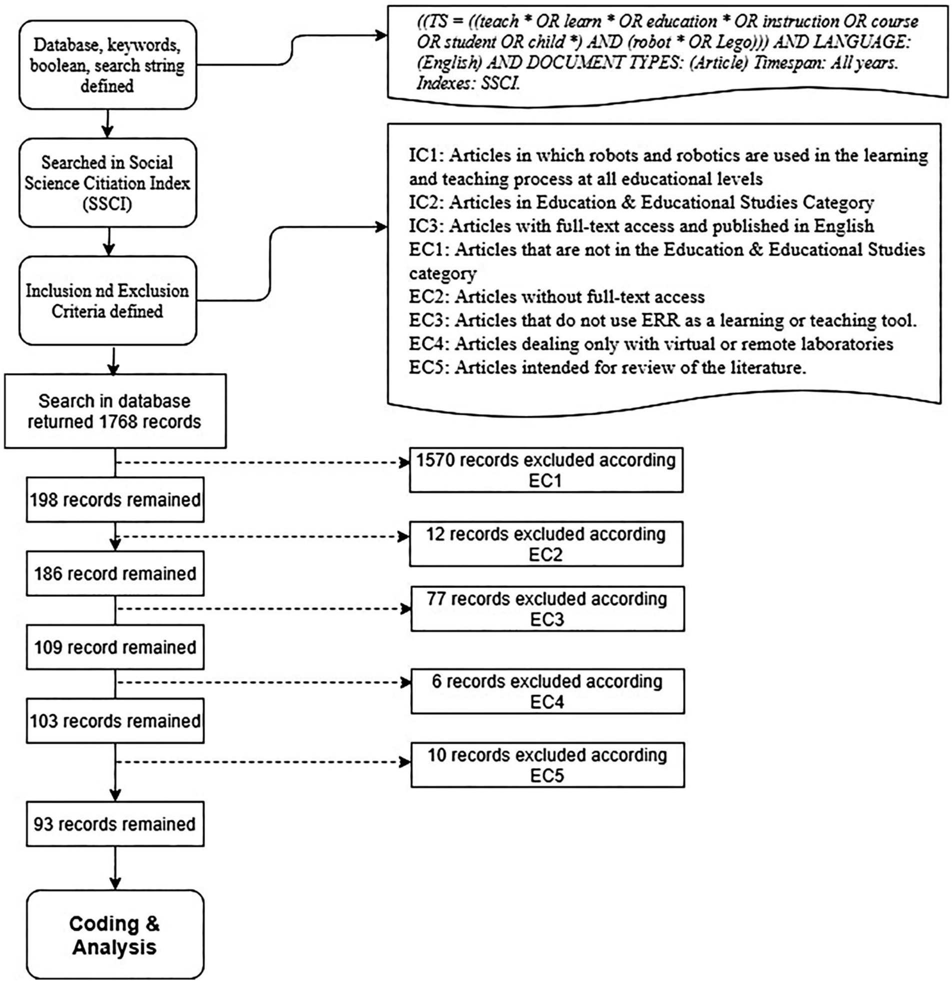

Figure 1. Search and study selection process.

2.3. Coding & analysis

The features that should be coded in the articles were selected for each research question. According to the research questions, 16 characteristics were defined by researchers. In the selection of these features, coding schemes in previous review studies were used.

For this, the components in the technology learning model for flipped classrooms developed by Lin and Hwang (2019) were examined. There are six components in this model: (a) Participants, (b) Research issues, (c) Learning strategies, (d) Adopted technologies and learning environments, (e) Application domains or learning objectives, (f) Research methods. The six components excluding the research methods in this framework, were used after making adjustments and adaptations according to the ERR in the current study. In addition, it was decided to code learning theories in addition to learning strategies. Finally, features to be coded for experimental studies have been added to the coding framework. As a result, seven components were identified for the coding framework. Explanations about the coded features are included in the following items:

- **Demographics:** Meta-data containing the article's year, the journal was published, and the keywords used were coded.

- **Participants:** Study groups were classified as kindergarten, elementary school students, middle school students, high school students, undergraduate/post graduate and mixed. Also, teachers and parents have been added to coding scheme as they are important stakeholders.
- **Research issues:** Classification approaches in the literature were surveyed to determine the studies' research issues (Lin & Hwang, 2019; Petersen et al., 2015; Wieringa et al., 2005). However, a need for a new classification scheme has emerged for ERR-related research issues. Therefore, in this study, different research issue categories were created to classify the studies related to ERR. For this purpose, the first author extracted the sentences in the articles with the intended purpose and processed them on the spreadsheet, and then created the raw category list by reading the entire article. Other authors re-examined the articles under categories. A consensus was reached on the names and scopes of the categories. As a result, 11 research categories were defined: intervention, exploration, opinion & perception, design & development, interaction, diffusion & adoption, professional development, group comparison, progression, prediction, instrument development.
- **Theoretical models and learning strategies:** The classification related to the theoretical framework consisted of 10 categories: constructivism, constructionism, experiential learning, self-directed learning, situated learning, self-determination theory, activity theory, authentic learning, adoption and the acceptance theories, and others.
- **Adopted Technologies and Learning Environments:** Studies on ERR are primarily classified as robots and robotics. Studies in which the robot is used are classified as tutor and learning companion according to the framework put forward by Mubin et al. (2013). Studies using robotics are categorised under four headings: (a) teaching basic robotics concepts, (b) structured problems, (c) ill-structured problems, (d) integration of robotics into the subject area.
- **Application Domain:** The distribution of ERR by subject area is divided into eight: (a) English, (b) science, (c) mathematics, (d) programming, (e) special education, (f) art, (g) other, (h) N /A.
- **Experimental studies:** Benitti's (2012) study was based on the selection of features to be coded for experimental studies. The study's intervention (independent variable), the experimental model, data analysis, data collection tools, dependent variable, and findings were extracted.

The coding and analysis process were carried out iteratively. Firstly, three authors extracted some articles to reach a common understanding of coding's classification options. Later, explanatory notes on how to code were added to the spreadsheet. In this way, the descriptive validity threat was tried to minimize by ensuring the form's objectivity. Three authors discussed together with the classifications that remained uncertain, and articles were retrospectively analyzed. After each discussion, the spreadsheet was updated, and a consensus was reached in all coding. A detailed explanation of how the search, coding and analysis process is done for repeatability is given.

3. Findings

3.1. What are the ERR research trends in terms of their research issues and demographics?

3.1.1. Demographics

The year, the study group's demographic characteristics, research objectives, and categories were presented in this section. The distribution of articles by years was given in Figure 2.

According to Figure 2, only seven out of the 93 studies selected for review were published in 2008 and before.

3.1.2. Participants

The distribution of articles by participant groups was given in Figure 3.

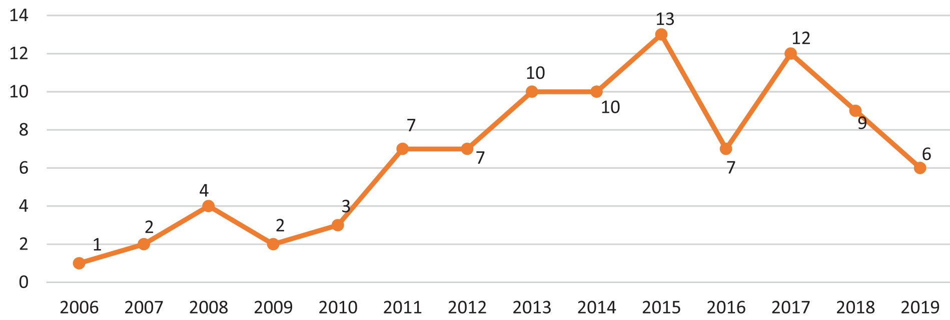

Figure 2. Distribution of the studies according to years.

According to Figure 3, the studies were carried out with special education, kindergarten, primary school, secondary school, high school, university students, teachers and parents. The study group was not specified in two studies because it was a design and development research. Studies were mostly conducted with mixed groups ($N = 21$). Also, the studies conducted in primary school ($N = 17$) and kindergarten ($N = 13$) were high. The frequency of studies with high school students seems to be relatively low ($N = 4$).

3.1.3. Research issues

The articles included in this review were classified according to their issues and research categories. Then, eleven research categories were emerged and presented in Figure 4.

As seen in Figure 4, the studies' research categories were scattered over a wide range but concentrated more on the studies that aim to study the effectiveness. The intervention category studies consisted of 34.4% ($N = 32$) of the studies. Explanations related to intervention, variables, data collection, and analysis in these studies will be given in detail in the findings section under RQ4. Studies in the exploratory category made up 17.2% of the articles included in the search. ($N = 17$). Research in this category seeks to understand learning experiences such as problem-solving and creative thinking. Articles in the opinions and perceptions category consisted of 13.9% of the selected papers. Studies in this category included students' and teachers' experiences,

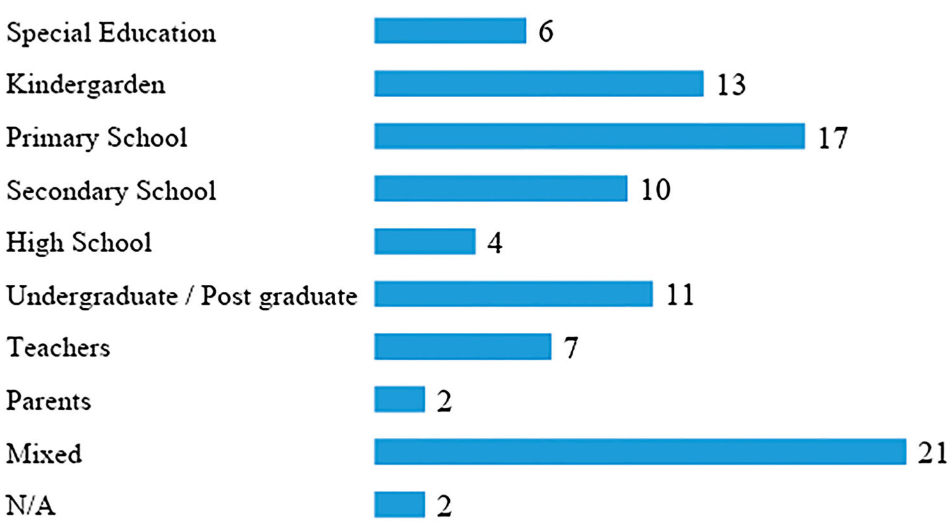

Figure 3. Distribution of the study groups.

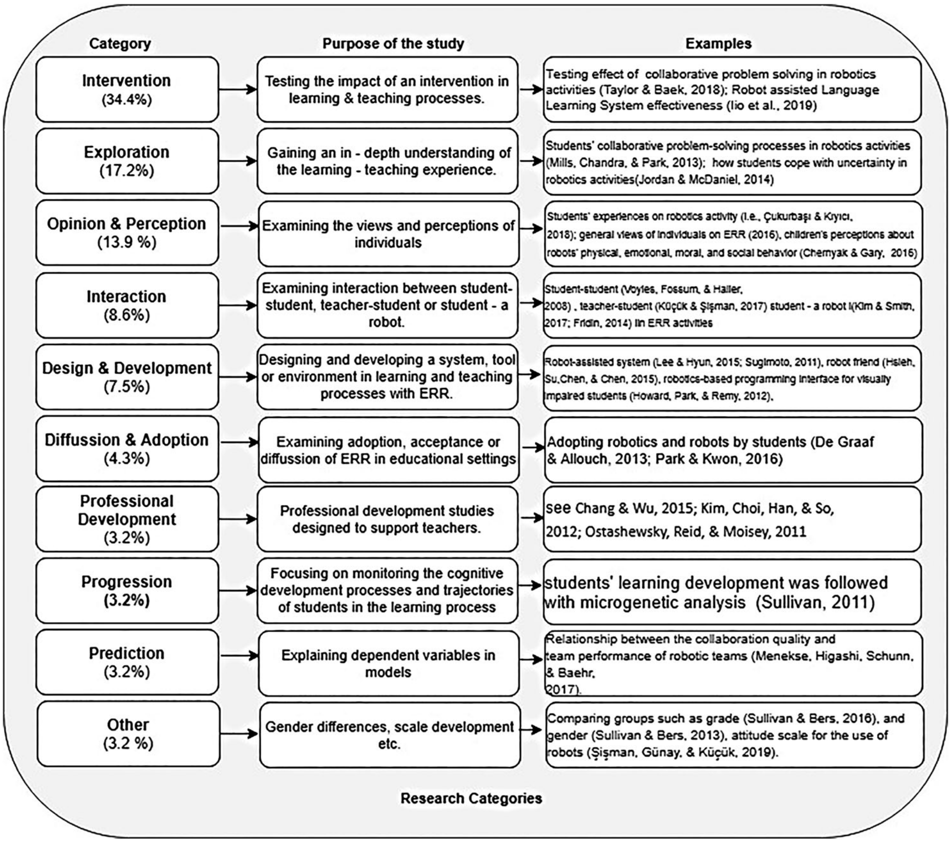

Figure 4. Research categories, issues and frequencies.

perceptions and general views of individuals on ERR. Interaction studies have consisted of 8.6% of studies. In these studies, the interaction between student-student, teacher-student or student – a robot was examined. Studies in the design and development category consisted of 7.5% of the studies, including robot-assisted system, digital learning playground, robotics-based programming interface for visually impaired students, and a web portal for teachers of robotics in STEM education.

There are also studies aimed at identifying the factors affecting the process of adopting robotics and robots by students and teachers. The studies' frequency in the professional development category ($N = 3$) was found to be relatively low.

3.2. Which theoretical models are the studies based on?

Primarily, the studies were investigated thoroughly as to whether they refer to any learning theory. No learning theory was cited in 40 of the 93 studies. On the other hand, we kindly invite the reader to be careful about frequencies in this section, as the question of whether the study has theoretical foundations requires an evaluation beyond just referring to theories. For this reason, it is a problematic approach to make an evaluation only on the journalism of the article while the quoted theory is reflected in the teaching-learning process. The fact that learning theory is not reported does not mean that it does not have a theoretical basis. Even if it is reported, there may be a subjective bias in its assessment.

Seventeen of the fifty-eight studies in educational robotics did not refer to any learning theory. Twelve of them referred to constructivism and constructionism. Additionally, experiential learning (Peleg & Baram-Tsabari, 2017), self – directed learning theory (Dolenc et al., 2016), situated learning (Shih et al., 2013; Verma et al., 2015), socially-oriented theories of learning (Jordan & McDaniel, 2014; Mills et al., 2013), dialogism (Sullivan, 2008), Feuerstein's Mediated Learning theory (Mitnik et al., 2009a), self-determination theory (Ayar, 2015), activity theory (Norton et al., 2007) was included in the studies as other theories.

Approaches such as metacognitive problem-solving guidance (Atmatzidou et al., 2018), problem-based learning (Gomoll et al., 2018; Gomoll et al., 2016; Çukurbaşı & Kıyıcı, 2018), collaborative learning (Gomoll et al., 2017; Menekşe et al. 2017; Hwang & Wu, 2014; Taylor & Baek, 2018), inquiry-based approaches (Cuperman & Verner, 2019) and one-to-one robotics teaching (Kazakoff & Bers, 2014; Küçük & Şişman, 2017) were used in the studies. Also, student-centered – instructor-led (Mcdonald & Howell, 2012) teaching model belonging to Fu et al. (2010) and the evidence-based didactic method based on constructivism was included (Castro et al., 2018).

Out of 35 studies related to educational robots, 23 did not refer to any learning theory. Constructivism (Burleson et al. 2018; Wei & Hung, 2011), authentic learning (Chen et al., 2013), situated learning (Chang et al., 2010a; Chen et al., 2013; Hung et al. 2015), and inquiry-based learning (Chang & Wu, 2015) were adopted in the studies in this category. Mazzoni and Benvenuti (2015) studied a kindergarten student's learning with a humanoid robot and his peer in a socio-cognitive conflict strategy. Özdemir and Karaman (2017) selected the principle of immediate correction of Skinner's programmed teaching method in question styles presented by the robot. The adoption and the acceptance theories were given in the studies (De Graaf & Allouch, 2013; Fridin & Belokopytov, 2014).

3.3. How and in what ways are ERR used in the research?

3.3.1. Adopted technologies and learning environments

Studies on ERR are primarily classified as robots and robotics. Educational robotics includes studies that point to how the student is programming a robot and learns about other disciplines. 58 of the 93 studies were carried out within this scope (62.4%). Robotic activities were examined under four headings (Figure 5).

On the other hand, studies in educational robots category focus on the individual's learning from the robot or with the robot through robot-assisted systems, humanoid or social robots. 37.6% ($N =$ 35) of the research were included in the educational robots' scope. Educational robots are used in two ways as a tutor and learning companion.

(a) Tutor: In studies focusing on educational robots as a tutor, robot-assisted systems are used in learning-teaching processes. Some of these systems are used in language learning (Hong et al., 2016; Iio et al., 2019; Lee et al., 2011), and some of them are used in special education (Krishnaswamy et al., 2014; Özdemir & Karaman, 2017). Mixed reality supported environments were used in some studies (Chang et al., 2010a; Sugimoto, 2011). Also, some studies emphasized the instructional design process and included robots as teaching assistants (Chang et al., 2010b; Wu et al., 2015).

(b) Learning companions: The studies in this scope focus on the individual's participation in learning activities with the robot. The educational robot can assume a friend's role in which the individual can speak English (Wang et al., 2013) and solve problems together while learning English words (Mazzoni & Benvenuti, 2015). Studies in this scope show that robots are used in the therapies of children with ASD (Pop et al., 2013) and improve their communication skills (So et al., 2016).

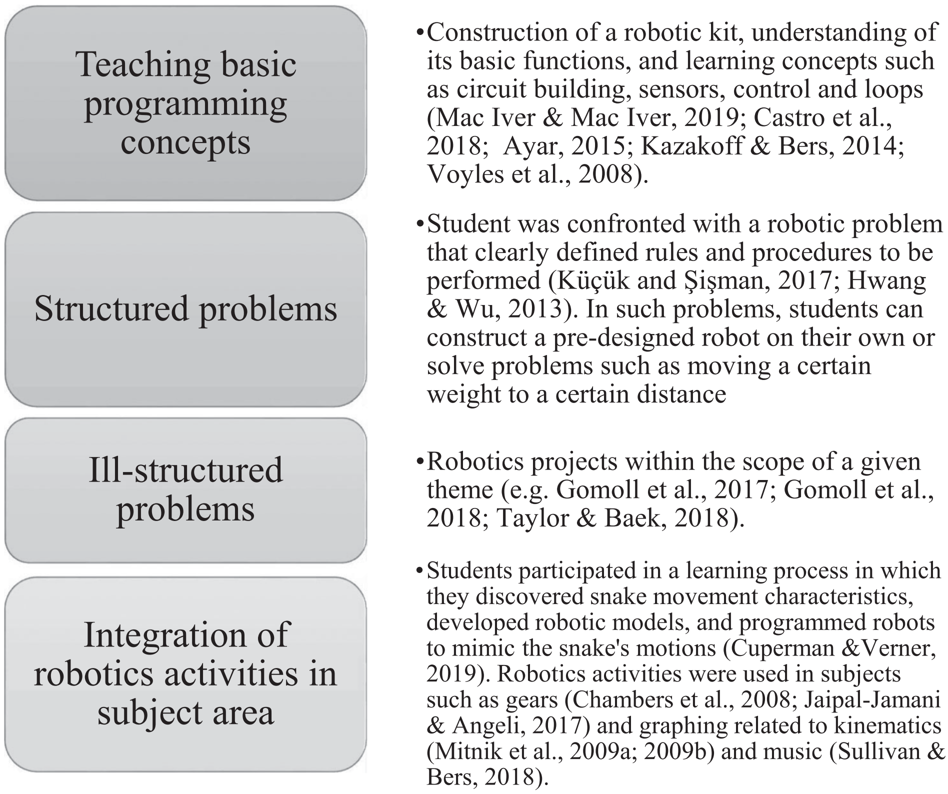

Figure 5. Ways of using educational robotics.

3.3.2. Application domains

The distribution of the application domains where ERR is applied was given in Table 2.

According to Table 2, there are 58 studies within the scope of educational robotics. There were 15 articles on general opinion, professional development, diffusion, and prediction, in educational robotics. The subject areas of the 33 were in the field of programming. As seen in Table 2, there are 35 studies within the scope of educational robots. Seven of these studies were carried out for the purpose of acceptance and diffusion of the educational robots, scale development, perception, and opinion. Approximately half of the remaining 28 studies were conducted in the English subject area. The low frequency of studies related to mathematics and science also attracted attention. Thus, educational robots are applied to the subject areas in a broader range, while robotics focuses more on programming.

Table 2. The distribution of educational robots and robotics related to application subject areas.

Subject Area	Educational Robots	Educational Robotics
English	13	–
Science	1	6
Math	1	–
Programming	–	36
Special Education	5	–
Art	1	1
Other (Reading, storytelling, behavioral task)	7	–
N/A	7	15
Total	35	58

3.4. What are the findings of experimental findings on ERR?

The results of the experimental studies on ERR were examined separately according to robotics and robots and explained below respectively.

3.4.1. Findings of experimental studies related to educational robotics

There are 15 experimental studies on educational robotics. Detailed information about these studies was given chronologically in appendix-1. Seven of the 15 studies tested the effect of a protocol including educational robotic activities (i.e. Castro et al., 2018; Jaipal-Jamani & Angeli, 2017; Kazakoff & Bers, 2014; Sullivan, 2008). In two studies, programming environments were compared (Okita, 2014; Özüorçun & Biçen, 2017). Educational robotics activity was applied to another subject area in four studies (i.e. Mitnik et al., 2009b; Sullivan & Bers, 2018). The effectiveness of the pedagogical approach with robotics was tested in the intervention in two studies (Atmatzidou et al., 2018; Taylor & Baek, 2018). In most studies, instruments consisting of closed-ended questions such as questionnaires, scales, and multiple-choice tests were used. Also, in some studies, open-ended problems were measured with rubrics. Thirty-two hypotheses were tested in 15 studies. More than half of these hypotheses ($N = 20$) were supported. The dependent variables in the studies can be examined in three groups: (a) Skills, (b) Affective characteristics, (c) Learning performance. Within the scope of their skills, eight hypotheses related to metacognitive awareness, computational thinking, sequencing, science process were tested. Except for one of these hypotheses, the rest was reported to be supported significantly. Nine hypotheses were tested within the scope of affective characteristics such as motivation, interest, enjoyment, and six of these hypotheses were proved, and three of them were not. In the context of learning performance in science, mathematics, and programming, 14 hypotheses were tested. Half of these hypotheses were supported, and half of them were not.

3.4.2. Findings of experimental studies related to educational robots

There were 17 experimental studies conducted about educational robots. The details of the studies were given chronologically in appendix -2. When the interventions were examined, seven of the 16 studies were used robots as tutors. Six studies were included robots as learning companions. Robots were used as teaching assistants in instructional technology design in two studies. In one study, the robot was used as a learning material by nursing students in learning patient transport skills (Huang et al., 2017). Of the 16 experimental studies, eleven were quasi-experimental, three were weak experimental, and four were true experimental designs. According to the studies' instruments, the individual's behaviours were evaluated in seven studies, and the questionnaires were used with the qualitative data in four studies. Besides, surveys were used in three studies. In the 16 studies, 47 hypotheses were tested. It was found that more than half of these hypotheses ($N = 34$) were supported significantly. 12 of the 14 hypotheses within the scope of learning English were confirmed. All hypotheses in two studies of the skills of students with special needs were proven. On the other hand, 9 of 14 hypotheses related to affective characteristics such as motivation and interest were supported, and five were not. Half of the six hypotheses related to interaction were supported ($N = 3$).

4. Discussion

The findings of the study were discussed under the headings of research problems.

4.1. What are the ERR research trends in terms of their research issues and demographics?

There was a significant increase in the last five years in the studies about ERR. More than half of the studies were published in the past five years. The first study included in the review was in 2006.

Indeed, 2006 is remarkable as it was the year that MIT released Scratch. It can be argued that the introduction of block-based programming with Scratch to educational environments facilitates robotic programming activities for younger age groups and makes it applicable to many teaching levels, including kindergarten. In this study, articles related to ERR were classified according to their objectives, and eleven research categories were created. Accordingly, studies were mostly performed in the intervention category. Approximately 35% of the articles aim to test the effect of an intervention involving ERR. There may be several reasons for this case. Recent review studies on educational robotics reported findings that have been proven and unproven in experimental studies using robotics and concluded that more experimental evidence is needed to reach clear conclusions about its effectiveness (Benitti, 2012; Xia & Zhong, 2018). Intervention studies in this category may have been based on the findings of these review studies. On the contrary, deterministic perspectives that technology as innovation will be sufficient for educational problems may have caused an increase in the number of studies. Among the studies in this review, exploratory studies' frequency after the intervention category was high. Exploratory research is a study that provides logical ways to examine and explain a limited section of reality and aims to understand how and in what ways the factors are associated in this process, thus helping to raise awareness by uncovering previously unsuspected connections and causal mechanisms (Reiter, 2017). It should be emphasized that exploratory studies contribute to the literature to understand what happened in processes such as problem-solving, knowledge construction, collaboration, and creativity in educational robotics activities. After the exploratory studies, the studies' frequency aiming to examine individuals' opinions and perceptions about ERR was relatively high. It can be predicted that examining the perceptions of children born in the digital age regarding whether the robot is alive or not will continue to be an important social and individual issue in the future. Contrarily, considering the critical roles of teachers in the learning-teaching process, it was observed that the number of studies in the professional development research category was relatively low. Moreover, designing and applying for the course by matching the technology appropriately with the appropriate pedagogy can confront the teacher with a challenging situation. In this regard, the studies aimed at teachers' professional development should be increased in the future. Studies in the category of diffusion and acceptance were mostly related to educational robots. Studies that examine the factors affecting the acceptance and adoption processes of robotics activities can be recommended in the future.

4.2. Which theoretical models are the studies based on?

Notably, studies on ERR do not include too many learning theories. In a study conducted to elucidate the claim that educational technology is under-theorized (Hew et al., 2019), 503 articles were analysed, and it was concluded that 41.55% of them did not have a trace of theory. Similar findings were reached in this study. The vast majority of research does not refer to any theory; part of it is half-open; very few studies show that the theoretical part is exact. While atheoretic studies focus on technology, how technology is used, and whether it affects learning outcomes, theoretical basis help to understand why technology affects learning outcomes, the mechanism behind the phenomenon, and its reasons (Hew et al., 2019).

4.3. How and in what ways are ERR used in the research?

In this study, two ways were covered in ERR usage: robotics and robots. Educational robots were mostly used in language learning, while educational robotics was mostly utilized in programming learning. Considering that the emergence of educational robotics is the concretization of mathematical concepts through programming and cognitive deepening (Feurzeig et al., 2011), the limitations of studies in which educational robotics have been applied to mathematical subjects should be taken into account. Also, the number of studies about robotics integrated with other disciplines was relatively less. However, the approach to the classification in this study may have caused this situation. The classification of educational robotics as an integrative role within this study's scope was made according to the reports presented about its integration with other disciplines. Although STEM was emphasized in some studies' titles and discussions, the operation was only about learning basic robotics concepts. In some studies, explanations about the open-ended problem solved by robotics were very limited or not at all. Therefore, it was necessary to explain the problem situation in detail, especially in robotic activities paired with inquiry-based learning, and to deepen the explanations regarding the integration with other disciplines. In conclusion, the authors recommended future studies on the use of ERR in different learning areas.

4.4. What are the findings of experimental findings on ERR?

In the introduction part of this study, the claims regarding the educational promise of ERR were compiled under four headings. These claims and experimental findings were compared and interpreted, respectively.

Claim 1. Educational robotics promote higher-order thinking skills

In the studies on educational robotics, it was determined that the dependent variables examined about higher-order thinking are collaborative problem solving, metacognitive awareness, computational thinking, science process skills, system thinking. The interventions that deal with robotics with the pedagogical approach are very few. In two experimental studies involving robotic activities with a pedagogical approach, hypotheses related to collaborative problem solving and meta-cognitive awareness were supported (Atmatzidou et al., 2018; Taylor & Baek, 2018). In other studies, the effect of robotic activities on computational thinking (Chen et al. 2017; Jaipal-Jamani & Angeli, 2017), graphic interpretation skills (Mitnik et al., 2009a; 2009b) were tested and supported experimentally. These findings support the claims regarding the development of higher-order thinking and computational thinking skills of educational robotics. Accordingly, designing and implementing interventions by taking a pedagogical approach will contribute more to the field.

Claim 2. Educational robots improve the social skills of the students

Two experimental studies on this claim positively affect students' social skills with special needs (Pop et al., 2013; So et al., 2016). In this context, it could be argued that the study groups should be diversified and, more experimental studies are needed. In studies conducted with educational robots, the students' interactions with robot-supported systems were analysed. Findings related to interaction opens an opportunity for further discussions. The quality of learner-robot interaction can be increased with the development of existing technological features and, personalization of this interaction may be an essential research direction in the future (van den Berghe et al., 2019).

Claim 3. Educational robotics and robots support the affective characteristics of students

The claim related to affective characteristics was included in both educational robotics and educational robot studies. However, some of these studies' hypotheses were accepted, whereas some were not supported. Also, there are insufficiencies in reporting validity and reliability of the instruments used to measure affective characteristics in educational robots' studies. It could be argued that it is required to examine the student's affective characteristics in learning and teaching processes involving educational robots with data collection tools whose validity and reliability were proven. In summary, more studies are needed to clarify these claims for both robotics and robots.

Claim 4. Educational robotics and robots contribute to learning performance

The findings related to the claims that ERR improves learning performance differ according to educational robotics and educational robots. In terms of educational robotics, findings on learning performance were shown that this claim is open to discussion. Mathematics success was considered a dependent variable in two studies, but it was not supported (Appendix 1). The effect of robotics in science learning is also open to discussion. As a result, more experimental evidence is needed to understand whether educational robotics improves learning performances. Experimental findings regarding educational robots support the claims, especially about foreign language learning performance. On the other hand, two hypotheses testing foreign language learning, such as conversation and reading comprehension, were not supported. Hypotheses regarding these two higher-level learning objectives in language learning need to be considered. Highlighting the role of very few studies on instructional design that includes educational robots is another point to be considered. Only two studies reported the robot itself will not cause educational outcomes, but it should be handled as an instructional design tool (Hung et al., 2013; Wu et al., 2015). Conducting studies with such approaches will contribute to the literature in terms of integrating educational robots with the learning-teaching process.

4.5. Implications

It was concluded that the majority of the articles examined in this study did not refer to a theoretical framework or that there were uncertainties in the application of the theory. Therefore, both practitioners and researchers should consider pedagogical approaches when designing learning-teaching processes using ERR. In studies examining the interdisciplinary role of ERR, it was determined that there were limitations in reporting how integration was achieved. Therefore, researchers need to deepen explanations about the integration of ERR into other subject areas and how the theoretical framework is put into practice. Also, it is noteworthy that the diversity of the claims is not sufficiently reflected in the experimental findings. This situation can be interpreted as the difficulty in not adequately evaluating the expectations promised by ICT in the technology integration literature (Sanders & George, 2017) continues in the case of ERR. Thus, it is necessary to take steps to evaluate the potential of ERR as an innovation. Researchers, decision-makers, and practitioners must first answer why ERR will be used then take part in the planning regarding how ERR should take place in learning and teaching processes. Also, some research gaps were revealed regarding ERR. Although experimental findings were reached regarding the claim that ERR improves learning, it was seen that there were inconclusive results. This highlights the importance of teachers designing and planning their lessons to support ERR subject area learning. In addition, researchers need to plan the intervention process within the framework of instructional design in studies related to ERR. It was seen that the experimental findings regarding the claims that the ERR supports the affective characteristics of the students are open to discussion. For this reason, teachers should follow the emotional processes of the students and support the students by considering the dynamic nature of the robotic classrooms. Although there are positive findings of the claims that educational robots improve social skills, it can be said that more studies are needed to clarify this claim. In addition, researchers need to focus on both the technological aspects of educational robots and the psychological factors behind the development of social skills. Supporting research findings have been found that educational robotic activities encourage higher-order thinking skills. However, it is important to design each intervention planned for the experimental and control groups according to different pedagogical approaches, including robotic activities, in order to reveal the cause–effect relationship.

4.6. Limitations and recommendations

In this study, the empirical findings in the literature on claims related to ERR have been compiled. However, the results obtained in this study draw attention to the aspects that should be considered for future research and identification of research gaps, rather than providing evidence of the authenticity of the ERR-related claims. As studies on ERR increase in the literature, meta-analysis studies can be conducted in the future on the authenticity of each claim. In addition, the length of the intervention process was not taken into account in the experimental studies examined. Future meta-analysis studies may consider this element in elucidating claims about ERR.

Also, particular attention should be paid to methodological limitations in the studies when comparing claims and experimental findings. Most experimental studies were involved quasi-experimental designs. This finding was similar to previous review studies (e.g. Xia & Zhong, 2018). Statistical models for controlling covariate variables that may affect the dependent variable were used in very few studies. Finally, the length, duration, participant groups, the robotic/robot kit used, and the experimental studies' pedagogical background also differ among the studies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix

Table A1. Experimental studies related educational robotics.

Reference	Intervention	Experimental Design	Data Analysis	Instrument	Dependent Variable	Supporting status
Mac Iver and Mac Iver (2019)	Attending STEM summer camp Groups: (E) Robotic (C1) Art (C2) Sport	Quasi-experimental with control group pre –post test	Hierarchical Linear Model	Absenteeism rates from school	School attendance	+
Atmatzidou et al. (2018)	Meta-cognitive and Problem solving guidance protocol Groups: (E) strong guidance (C) minimal guidance	Mixed Method Quasi-experimental 1 × 2 design	Paired sample t-test ANCOVA (pretest as covariate)	Questionnaire Think aloud protocol Interview Observations	Metacognitive awareness	+
Taylor and Baek, 2018	Collaborative problem solving in robotics Groups: Collaborative groups with (E1) Classroom discussion (E2) Assigning groups roles (C) previous instructional practice with collaborative groups	Experimental 2 × 3 design	2 × 3 analysis of covariance (pretest covariate)	Survey Skill assessment form	Learning motivation (robotics)	+
					Collaborative problem solving	+
					Science process skills	+
					The findings above is for the experimental group assigned group roles.	
Castro et al. (2018)	Educational Robotics Activity	Quasi-experimental single-group pre–post design	Wilcoxon signed-rank	A questionnaire composed multiple choice items	Robotics achievement	+
Sullivan and Bers (2018)	An integrated curriculum of robotics and art	Quasi experimental single group mid test – post test	Paired sample t-test	Open ended questions assessed	Programming concept knowledge	+
Chen et al. (2017)	Robotics curriculum	Single group pre –post test	Paired sample t-test	Instrument with multiple choice items and open – ended questions	Computational thinking	+
Özorçun and Biçen (2017)	Programming and algorithm instruction Groups: (E) Robotics (C) Robot action on the computer with a game program	Quasi experimental 1 × 2 design	Paired sample t-test	Instrument with multiple choice items and open – ended questions	Programming achievement	+
					Experimental pretest / posttest significant; control pretest posttest is not significant	
Jaipal-Jamani and Angeli (2017)	Engagement in robotics activity	Quasi experimental single-group pretest-posttest design	Paired sample t-test	Pre post assessment including Open ended questions Questionnaire	Teaching Self-efficacy in Teaching robotics	+
					Science Concepts	+
					Computational thinking	+
Kim et al. (2015)	Robotic programming and the developing lesson plans using robotics	Mixed Method Single group pre-posttest design	Paired samples t – test Wilcoxon	Classroom observation; Participant interview Survey Lesson	Autonomous motivation	+
					Enjoyment	+
					Interest in Technology	+

(*Continued*)

Table A1. Continued.

Reference	Intervention	Experimental Design	Data Analysis	Instrument	Dependent Variable	Supporting status	
			Signed-Rank Test	plan scores Multiple choice test Questionnaires	Interest in Mathematics		+
					Interest in STEM Careers		+
					Interest in Science	+	
					Interest in Engineering	+	
					Science Knowledge		+
					Technology Knowledge		+
					Engineering Knowledge		+
					Mathematics Knowledge		+
Okita, 2014	Programming instruction Groups: (E) Visual programming (C) syntactic programming	Experimental Mid-test – Post test 1 × 2 design	ANOVA	Exams including programming problems	visual programming performance – Mid Test		+
					Syntactic programming performance – Mid – Test	+	
					visual programming performance – Posttest	+	
					Syntactic programming performance – Post – Test		+
					The findings above is for the syntactic programming group		
Kazakoff and Bers (2014)	Curriculum of activities, including a hybrid graphical-tangible programming interface	Single group pre –posttest design	Paired sample t-test	Picture story sequencing assessments	Sequencing	+	
Shih et al. (2013)	Science and Technology Course. Groups: (E) Robotics activity, (C) ICT integration	Quasi experimental pre-posttest with a control group design	ANCOVA (pre-test as covariate)	Multiple choice test	Learning performance (science)	+	
Mitnik et al. (2009)	Computer assisted Graph Plotter Activity. Groups: E) robotics (C) simulation	Quasi experimental pre-posttest with a control group design	ANCOVA (pre-test control)	Multiple choice test	Graph interpretation skills	+	
Sullivan, 2008	Robotics activity	Mixed Method Single group pre –posttest design	Paired samples t-test	Video recordings Open ended questions assessed with rubric	Systems understanding	+	
Lindth and Holgersson (2007)	Robotics activity implemented by the teacher Groups: (E) Robotic activities (C) previous instructional practice	Mixed Method Quasi experimental with control group pre – posttest design	Independent samples t-test	Observation, interviews Memos Multiple choice test	Math achievement		+

Table A2. Experimental studies related educational robots.

Reference	Intervention	Experimental Design	Data Analysis	Instrument	Dependent Variable	Supporting status	
Iio et al. (2019)	Robot assisted Language Learning System	Single group repeated measures	Repeated ANOVA	Speech unit	Number of words	+	
					Rate of grammar/lexical errors	+	
					Number of words per minute	+	
					Length of silent pauses	+	
					Segmental aspect of pronunciation	+	
					Segmental aspect of pronunciation	+	
					Task achievement (conversation with robot)		+
Huang et al. (2017)	Using a Robot Patient for Nursing Skill Training in Patient Transfer Groups: E1: transfer human simulated patient, E2: robot patient; C1: transfer human simulated; C2: robot patient	Experimental Three factor $2 \times 2{\times}2$ mixed	Mixed ANOVA Paired samples t-test	Checklist for skill performance	Patient transfer skill		+
					* Paired samples t-test result proved both experimental and control group		
So et al. (2016)	Video modelling with robot animation	Single group repeated measures	Repeated ANCOVA(visual motor coordination & visual perception controlled)	Video recordings including children gestures	Gestural skills	+	
Hong et al. (2016)	Robot-Assisted Language Learning framework Groups: (E) Robot assisted system (C) Previous instructional practice	Quasi experimental with control group posttest design	Independent samples t-test	Test including reading, writing, speaking and listening Survey	Learning performance (English)	+	
					Motivation (learning material)	+	
Hsiao et al. (2015)	Language learning with robot Groups: E: Learning activity with intelligent robot, C: Learning activity with tablet PC	Quasi experimental with control group pre-posttest design	ANCOVA (pretest controlled)	Behaviors in learning process	Reading comprehension		+
					Storytelling ability	+	
					Word recognition	+	
					Retelling story	+	
			Paired samples t-test		Gazing		+
					Bi-directional interaction	+	
					Reading or singing		+
					Replying question	+	
					Other		+
Wu et al. (2015)	Instructional design using a teaching assistant robot Groups: (E) interaction with robot, (C) no interaction with robot	Mixed Method Quasi experimental with	Independent samples t-test	Multiple choice test Questionnaire Interviews	Learning outcome (English)	+	
					Motivation and interest (for English)	+	

(*Continued*)

Table A2. Continued.

Reference	Intervention	Experimental Design	Data Analysis	Instrument	Dependent Variable	Supporting status	
		control group pre-posttest design		Observation Video recordings			
Han et al. (2015)	Augmented reality infused robot assisted dramatic play Groups: (E)Robot group, (C) Computer group	Quasi experimental with control group posttest only design	Independent samples t-test;	Questionnaire	Interest in dramatic play	+	
					User friendliness		+
					Self-engagement		+
					Environment engagement		+
					Collaboration with media		+
					Media function		+
					Empathy with media	+	
Hung et al. (2015)	Situated embodiment-based learning system Groups: (E) Situated Embodiment based strategy (C) Embodiment based strategy	Quasi experimental with control group posttest design	Independent sample t-test (no significant differences between group according to letter-number sequencing test)	Task performance test Questionnaire Brainwave headset	Learning performance (flag semaphore)	+	
					Attention	+	
					Extrinsic cognitive load	+	
Chin et al., 2014	Educational robot based learning system Groups: (E) robot assisted learning system, (C) PowerPoint based learning system	Mixed Method Quasi – experimental pre-posttest design	Independent sample t-test	Multiple choice test Questionnaire Observation Interview	Learning performance (Science)	+	
Krishnaswamy et al. (2014)	Robot-mediated visual motor program Groups: (E) visual motor program and occupational therapy, (C) Traditional occupational therapy	Experimental With a control group pre – posttest design	Independent samples t-test	Test for Visual Motor Integration	Visual motor integration	+	
Chen et al. (2013)	Implementation Digital Learning Playground. Groups: (E) digital learning playground, (C) Previous instructional practice	Experimental with a control group pre-posttest design	Independent samples t-test	Questionnaire	Learning performance	+	
Hung et al. (2013)	Robot assisted language learning. Both groups assigned to robot teaching assistant with different instructional designs	Quasi Experimental With a control group pre – posttest design (Random assignment)	Repeated Measures ANOVA, ANCOVA	Survey	Sustainability of learning motivation	+	
					Learning performance	+	
					Continuance intention	+	
Wang et al. (2013)	Framework with tangible robot companion for English conversations (E) tangible companions (C) Previous instructional practice	Mixed Method Quasi experimental with control group pre – posttest design test	Paired & independent samples t-test	Cloze Test Speaking task assessed with rubric Observation Interview Survey	Learning performance (English) Independent groups t-test is not significant for pre-test and post-test Paired samples t-test meaningful for both groups		+
Pop et al. (2013)	Social story delivery for ASD Children. Groups: (E1) Social Robots (Ê2) Computer Display (C) did not received any intervention	Quasi experimental (Random assignment) with control group	Mann Whitney U	Behavior Assessment using video recording	Social interaction (E1 & C)	+	
					Social interaction (E1 & E2)		+
					Social interaction (E2 & C)		+
			Independent sample t-test		Constructivist learning	+	

Wei and Hung (2011)	Learning system with robot. Groups: (E) Robot as learning companion (C) Previous instructional practice	Mixed Method Quasi experimental with control group pre-post design		Questionnaire Observation Interview	Experiential learning Joyful learning	+ +	
Lee et al. (2011)	Robot assisted language learning system.	Single group pre-posttest design	Paired samples t-test	Multiple choice test Speaking task assessed with rubric Questionnaire	Listening performance (English) Speaking performance (English) Affective effects (satisfaction, interest, confidence, motivation)*	+ + N/A	 N/A
Chang et al. (2010a)	Robot integrated mixed reality learning environment Groups: (E) Physical robot, (C) Virtual robot	Experimental with control group pre-post test	Independent sample t-test	Questionnaire	Learning performance Sense of authenticity Engagement Learning motivation	 + + +	+

*Paired samples t test performed individually for the items of the survey.