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Review

Systematic Review of Research Trends in Robotics Education for Young Children

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Abstract: This study conducted a systematic and thematic review on existing literature in robotics education using robotics kits (not social robots) for young children (Pre-K and kindergarten through 5th grade). This study investigated: (1) the definition of robotics education; (2) thematic patterns of key findings; and (3) theoretical and methodological traits. The results of the review present a limitation of previous research in that it has focused on robotics education only as an instrumental means to support other subjects or STEM education. This study identifies that the findings of the existing research are weighted toward outcome-focused research. Lastly, this study addresses the fact that most of the existing studies used constructivist and constructionist frameworks not only to design and implement robotics curricula but also to analyze young children's engagement in robotics education. Relying on the findings of the review, this study suggests clarifying and specifying robotics-intensified knowledge, skills, and attitudes in defining robotics education in connection to computer science education. In addition, this study concludes that research agendas need to be diversified and the diversity of research participants needs to be broadened. To do this, this study suggests employing social and cultural theoretical frameworks and critical analytical lenses by considering children's historical, cultural, social, and institutional contexts in understanding young children's engagement in robotics education.

Keywords: educational robotics; robotics for early childhood education; educational technology

1. Introduction

What does robotics education offer that has gained special attention from educators and researchers? Robotics education provides learners with practical experiences for understanding technological and mechanical language and systems; accepting and adapting to constant changes driven by complex environments; and utilizing knowledge in real situations or across time, space, and contexts [1]. In addition, along with the growing attention to STEM (Science, Technology, Engineering, Mathematics) education, robotics has been suggested as an innovative solution [2,3]. Regardless of the economic and societal needs for new types of innovative and knowledgeable citizens, robotics has the attention of scholars as a means of "empowering learners" and providing "authentic learning". By allowing learners to engage in the process-oriented learning experiences of robotics, young students can take initiative roles as co-constructors of learning, not as passive knowledge receivers nor technology consumers [4].

In this paper, we refer to robotics education as the application of educational robots in a teaching and learning context [5]. In other words, robotics education teaches about robotics or other subject areas by adopting educational robotics technologies. In recent years, studies have attempted to present the potential of robotics education even for young learners [6,7]. In addition, researchers have tried to suggest concrete methods of developing and implementing a robotics curriculum [8]. However, research on robotics education for young children is still in its early stages. Many previous studies have examined the technological properties of educational robots or robotics curricula rather than learners. In addition, the advantages of the educational robots have been generalized, without recognizing the different types of educational robots. Comprehensive and detailed investigations of how young children actually engage with educational robots and what they learn through robotics education are still needed [9].

Different types of educational robots have different appearances, structures (hardware), systems (software), and functions (behavioral outcomes) [10]. These features play an important role in determining the curricula, the instructional activities, and the learning objectives. Educational robots can be categorized as robotics kits, social robots, and toy robots [11]. Robotics kits are programmable construction kits. Robotics kits allow students to create, build, and/or program robots [11]. Social robots are based on artificial intelligence and autonomous behaviors. Social robots include Socially Interactive Robots (SIR) and Socially Assistive Robots (SAR) [12]. The key feature of social robots is that they can communicate and interact with students [13]. Toy robots are ready-made commercial robots for entertainment and play [14].

Considering the different types of educational robots, we targeted robotics education using robotics kits in a teaching and learning context. We included research in robotics education using social robots and toy robots in defining robotics education. We acknowledge that social robots have been used for teaching young children in kindergartens and schools [15]. In addition, some research applies social robots in teaching specific contents (e.g., geometry and literacy) [16,17]. Nevertheless, while the robotics kits engage young children in learning through designing, constructing and programming (operating) robots, social robots engage young children in learning different subjects through their social interaction with robots. Compared to robotics kits, the existing literature on robotics education with social robots has focused more on the efficiency of interactive and autonomous properties of the social robots for teaching and learning. For this reason, we selected the literature on robotics education using robotic kits as the main target for our review.

In this paper, we aim to draw a map depicting research trends in young children's robotics learning by reviewing existing studies that place more emphasis on young learners (Pre-K and kindergarten to 5th). By systematically reviewing the existing literature on robotics education for young children, we attempt to identify key research themes in robotics education and to outline gaps in the previous research.

2. Method

2.1. Data Collection

This study aims to elicit meaningful research trends through reviewing existing literature about robotics education for young children. To establish a reliable literature review, we referred to the systematical review process suggested by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [18]. To collect relevant studies, seven explicit criteria were set based on the following keywords; age, contents, research type, technologies, research setting, publication year and publication type.

As for age, our study mainly targets preschool- and kindergartener-age groups. However, the number of international studies targeting kindergarteners and preschoolers was relatively very small. Thus, to conduct a more comprehensive review, we included international studies which focused on Pre-K through 5th or 6th grade.

We searched for empirical studies that provided young learners with robotics education programs and curricula. In addition, we selected journal articles that regarded robotics education as a learning objective and subject matter—in other words, as a kind of discipline. In addition, we included studies that viewed robots as educational tools for teaching and learning other disciplines such as literacy, math, science, and arts. As for research types, both quantitative and qualitative studies were included in this review study. However, conceptual papers, review papers, and book chapters were excluded.

In addition, as mentioned earlier, we included studies which employed robotics kits but did not involve social robots such as Socially Interactive Robots (SIR), Socially Assistive Robots (SAR) or intelligent robots. Robotics kits typically consists of different construction parts (e.g., sensors, controllers, actors) and graphic-based programming interfaces that allow children to construct, operate, or program robots [19]. Because we paid attention to young children's robotics-specific learning and pedagogical applications of robots, we excluded research that used social robots in this study. If the research used only software programs, iPads, or computers without physical robotics kits, those studies were also excluded.

We included both informal and formal settings in which children experienced robotics education programs or robotics activities. As for the years of publications, we limited our study to the last 10 years—between 2006 and 2017. Finally, our search for this review was limited to journal articles and conference papers. Only articles written in English were considered.

Based on these criteria, we searched for articles in four online databases: ERIC (Educational Resources Information Center), Science Direct, Springer Link, and Google. While utilizing "Robotics", "Children", "Education", and "Kindergarten" as our main keywords for data searching, we adopted specific search protocols to set sub-disciplines or limited topics. As Figure 1 shows, we found 759 articles and papers via the four databases at the initial identification stage.

Although we searched for existing research with specific criteria, we got some non-relevant or overlapping results. Through several screenings, we reviewed the abstracts of the articles and we excluded the following types of articles from this literature review study: (1) duplicate studies by exactly the same authors; (2) articles that aimed at investigating the effects of robotics kits and robotics environments with the objective of rehabilitation or with a clinical approach; (3) articles that targeted teachers as the main participants; (4) studies which used only software programs with virtual robots (not physical robots); and (5) research that included young children only for the purpose of user tests to develop robotics technology. Overall, 47 relevant articles were finally selected for our analysis (Figure 1).

2.2. Data Analysis

In the process of analyzing 47 articles, we read the whole of each article and outlined the basic information presented. We comprehensively reviewed each research study for the following key characteristics: ages of participant children, types of educational robots employed, research methodologies, and theoretical frameworks (see Appendix A). Although we did not present key findings in Appendix A, we identified key findings of each reviewed study and included the summarized findings in our analysis. Then, we analyzed and systematically categorized patterns of our analysis results. In the findings section, we present our review of the research on young children's robotics learning. Although the findings present fairly summarized results with relevant references, they also include our opinions and discussion.

3. Results and Discussion

To gain a comprehensive map of young children's robotics learning and understand the current state of research in that area, we set research questions for this literature review related to the following three aspects: (1) definitions of robotics education; (2) key findings of the research on young children's robotics learning and factors or conditions relating to young children's robotics learning; and (3) theoretical and methodological features of the research. According to each question, the major points of our review are presented here.

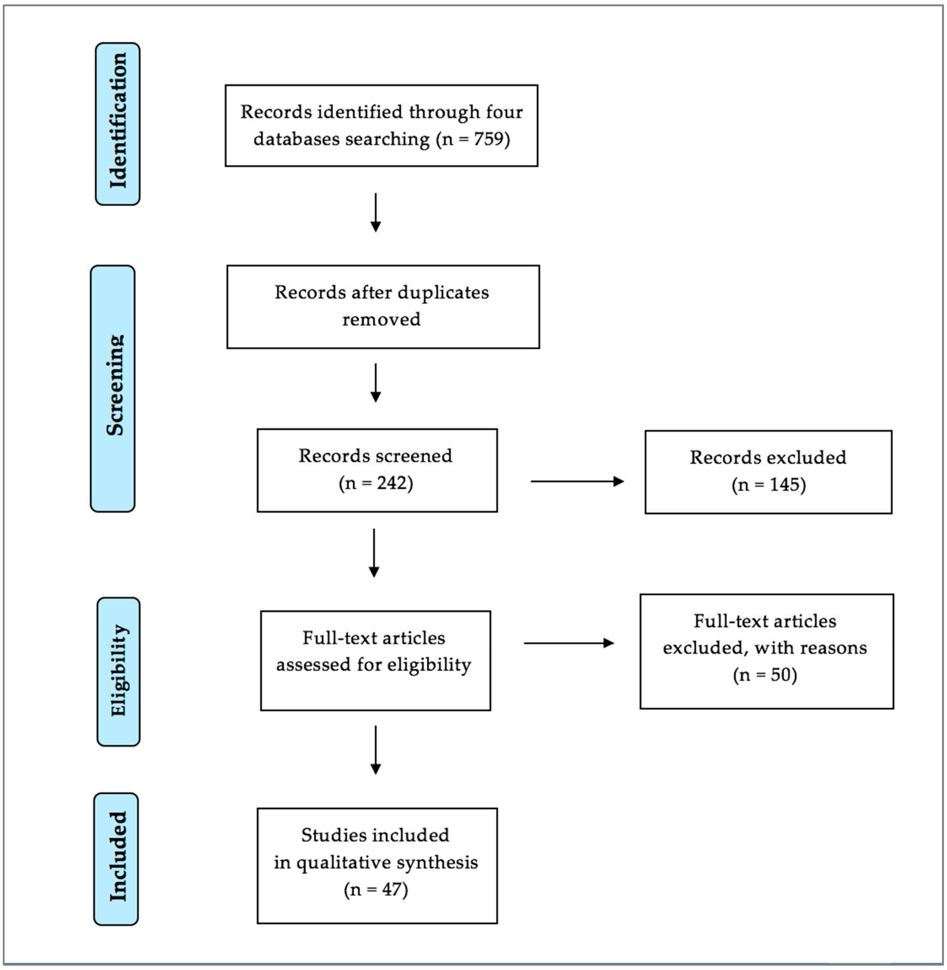

Figure 1. The systematic review process adopted and adapted from Moher, Liberati, Tetzlaff, Altman, and the PRISMA Group [18].

3.1. The Definitions of Robotics Education for Young Children

3.1.1. Perspectives on Robotics in Early Childhood Education

Before addressing how each study defined robotics education, we found it necessary to begin by establishing the position of robotics in education. The reviewed studies established different educational purposes for employing robotics. Our first question then was "How does the existing literature locate robotics in connection with early childhood education?"

Within the scope of our analysis, we noticed that the existing literature took two perspectives in positioning robotics within an educational context. The first perspective regarded robotics as a means or a technological environment to teach other subjects. For example, six studies among the searched 47 studies adopted this perspective on robotics programs (see Table 1).

Commonly, the research positions robotics as an effective tool to motivate young learners and to provide tangible materials for learning. As an instrumental approach to robotics, these studies designed their research by employing robotics curricula to support the existing curricula of the targeted subjects. In addition, these six studies focused on the technological traits (e.g., mechanical bodies of educational robots) of robotic manipulatives. In such cases, contents and teaching objectivities of other disciplines were prioritized. For example, Chambers, Carbonaro and Murray showed that robotics activities (constructing and programming Lego Mindstorms kits) were effective in helping 4th graders to learn gear functions and mechanical advantages [25]. The robotics activities were integrated with the existing science units. In this way, the six studies tended to place robotics in a secondary position for serving other subject areas.

Table 1. Studies that used robotics to teach other subjects.

Authors	Age	Robotics Activity	Targeted Subject
Cacco and Moro [20]	6	Programming	Early Science (Botany)
Datteri, Zecca, Laudisa, and Castiglioni [21]	7	Construction and Programming	Science (Scientific research skills)
McDonald and Howell [22]	5–7	Construction and Programming	Early Literacy and Numeracy
Wei, Hung, Lee, and Chen [23]	7	Construction and Programming	Mathematics (Multiplication)
Highfield [24]	3–4 and 6	Programming	Early Math (Mathematical Problem-Solving)
Chambers, Carbonaro, and Murray [25]	9–10	Construction and Programming	Science (Wheels and levers)

With regard to the integration of robotics in school contexts, we suggest that this view—robotics as a means of support to teach other subjects—needs to be supported by further studies about not only how to adopt robotics in school contexts and but also how to adapt robotics within regular lessons and existing curricula of other subjects. It is necessary to identify what learning topics, objectives, and contents of different subjects can be connected and integrated with robotics [26]. In addition, because this perspective employed the technological traits of robotics, further research is needed to examine what specific teaching methods and pedagogical aspects need to be considered when adopting different types of robotics kits [27].

The second perspective on robotics viewed robotics as a tool to teach robotics itself. The remaining studies (41 articles) positioned robotics as a discipline that was taught to young children (see Appendix). For this reason, almost all of the studies specifically elaborated on their robotics curricula, activities or modules. In particular, we want to emphasize that this view was related to STEM education. By referring to STEM education, this line of research was concerned with the interdisciplinary nature of robotics. The reviewed literature did not explicitly reveal how they positioned robotics in educational contexts. However, by analyzing the references and conceptual frameworks that the studies mentioned, we found that the 41 studies we reviewed elaborated on teaching objectives, teaching contents, or teaching methods of robotics education in connection to STEM education. This perspective was based on the premise that robotics education shares common teaching contents and objectivities with STEM education. This is why this line of research argued that robotics education can be the best discipline to access STEM education.

However, this view—robotics as a tool to teach robotics itself—needs to clarify the position of robotics in connection with STEM. Regarding robotics as a discipline relevant to STEM education, we identified that the existing studies took two different stances. As Figure 2 presents, the former perspective considered robotics education as a sub-discipline of STEM education (see Figure 2a). On the other hand, the latter viewed robotics education as a discipline that shares many common teaching contents with STEM education but also has distinct teaching contents and features (see Figure 2b).

In fact, we admit that it is not easy to differentiate between the two perspectives. Even within the field of STEM education, there is ongoing controversy regarding how to view the inter-relationships among the four disciplines [28,29]. We do not think that the two perspectives on robotics in connection to STEM education are a true dichotomy. Robotics education can be a subject with an independent curriculum to teach robotics itself. At the same time, because of its cross-disciplinary nature, a robotics curriculum can be a sub-discipline to teach concepts and practices that the STEM disciplines aim to teach [30].

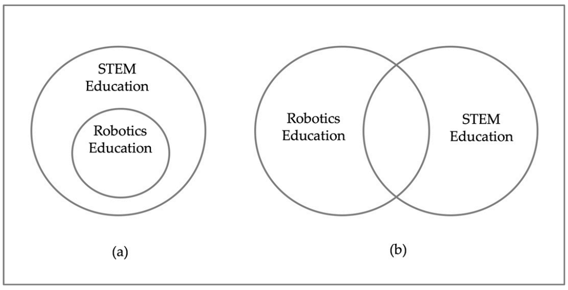

Figure 2. (**a**) Robotics education as a part of STEM education; and (**b**) robotics education as a subject.

For example, Sullivan, Bers, and Mihm implemented a robotics education program for 4–7-year-old children by using KIBO, a type of educational robot [31]. In this study, the children engaged in programming and constructing the KIBO robot. Through the programming practice, the children were able to learn computational thinking skills and ideas (e.g., algorithms and modularity). In this case, the robotics education program provided the children with the opportunity to acquire digital literacy, which is highlighted in STEM education [30]. In addition, the children engaged in the distinct practice of robotics education (e.g., understanding the mechanical and systematic structures of robots, designing robots, and building robots) by constructing robots [4]. Thus, in this study, robotics education as means to teach STEM and as a discipline to learn robotics were not opposite but rather compatible.

In reality, it was not a simple task to figure out how the existing literature had defined robotics education. The existing studies presented their robotics curricula in detail; however, they did not clarify their perspectives on robotics education in their research contexts. Even in cases that revealed their perspectives, the studies tended to focus on the positive learning outcomes (or effects of robotics education) they identified across disciplines. Thus, existing literature has depicted robotics education as very broad and versatile. This may be because robotics education is a relatively new emerging area; thus, much discussion about definitions of and the nature of robotics has been in process. In addition, the cross-disciplinary nature of robotics may contribute to maximizing the advantages of robotics in educational contexts. However, we point out here that it has resulted in some confusing and obscure maps of robotics education. Therefore, we suggest that the positional distinction of robotics in each study can help to justify the value of robotics education for young children and to outline what robotics education is and how to teach it.

3.1.2. Defining Robotics Education in Terms of STEM Literacy

Then, how does existing literature define robotics education in connection to STEM education? Unfortunately, most of the articles did not explicitly define robotics education for their studies. Thus, for this study, we attempted to use the concept of "*literacy*" as a framework to identify the definitions of robotics education that the reviewed research implicitly suggested.

In general, in STEM areas, literacy means more than the ability to read and write in scientific, mathematic, or technologic language [32]. Literacy is a frame to delineate key capabilities that each discipline expects learners to reach. Of course, literacy mirrors the distinct values and characteristics of each discipline [33]. While each concept of literacy in the STEM disciplines is unique (e.g., science literacy, mathematic literacy, engineering and technologic literacy), we found that the literacy frame describes two key aspects to define each discipline [34]: (1) knowledge and skills (practice) that learners need to learn and be able to use; and (2) the methods and purposes with which learners are expected to deal with them.

We analyzed the selected studies considering these two aspects of literacy. Again, as we mentioned earlier, the reviewed literature did not articulate a definition of literacy specific to robotics education. Rather, the authors usually elaborated on the contents of their robotics curriculum. For this reason, we used the curricula as sources of definitions of robotics education. For example, Sullivan and Bers implemented an eight-week robotics curriculum for pre-K to 2nd graders in their research to examine the learning outcomes of the robotics program [35]. The curriculum established core ideas for each activity as a kind of target goal (e.g., the concept of robots, different types of sensors and actors, commands for programming, and programming concepts such as repeated loops and conditional branches). In this way, the detailed curricula gave us information to identify how the research had framed and defined robotics education.

Considering the first aspect of literacy (knowledge and skills that learners need to learn and be able to use), we categorized the content areas of the robotics curricula in the reviewed research as follows: (1) concept (knowledge) domain; (2) practice (skills) domain; and (3) attitude (disposition) domain. Paying attention to sub-domains, existing studies shared some components with STEM disciplines to set scopes and types of contents for robotics education. Robotics education in the existing literature encompassed the crosscutting knowledge and skills in STEM areas such as subject-oriented knowledge (e.g., knowledge of physics) and cognitive skills (e.g., analyzing, classification, and prediction). A consideration of the practice domain, problem-solving process, engineering design process, and scientific inquiry skills characterized robotics education as a part of STEM [36].

On the other hand, given that the reviewed literature positioned robotics education in connection with STEM, it was interesting that the articles did not always share all components with STEM. A large portion of the content was directed toward robotics-intensified knowledge and skills. To be specific, existing studies included knowledge of robots (e.g., physical parts of robots, functions of parts of robots) and understanding of systems of robots as components of robotics education [37–39]. In terms of application of knowledge, the robotics-intensified knowledge was not merely secondary or background knowledge. Rather, the knowledge domain was closely related to robotics practices (such as designing, constructing, and operating robots) [40]. Thus, the robotics-intensified knowledge domain was not only fundamental but also differentiated robotics from overlapping domains within other STEM disciplines. In addition, the robotics-intensified domain can be helpful to shed light on the distinct nature and advantages of robotics education.

In regards to the robotics-intensified practice domain, we emphasize that the robotics-intensified domain had limitations, especially for characterizing robotics education. The main limitation we notice was an emphasis on programming to the exclusion of other skills. "*Robotics*" can be generally defined as an area that deals with the design, construction, operation, and application of robots and robotic systems [41]. Thus, the robotics-intensified practice needs to embrace skills for designing, constructing, operating, and applying robots and its systems. However, programming practice was mainly included in the operating part within robotics. Thus, the robotics-intensified practice was unbalanced. Of course, the existing studies included skills for constructing robots as robotics-intensified practice. However, compared to programming, only a few articles mention the practice of constructing [23,42–45]. Moreover, programming practice has been gradually developed; however, existing studies do not explain fully what specific elements (e.g., skills for stability) of robot-constructing practices need to be incorporated in the programming practice.

In addition, we want to point out that the attitude domain need to be clear in defining robotics education. It appears to be both redundant and featureless. As for redundancy, the attitude domain of robotics has been defined as a cluster of general good things. For example, collaboration as an interpersonal attitude was the most common component that almost every STEM discipline stressed [3,46]. Most of the articles we reviewed repeatedly mentioned collaboration as an important outcome of robotics education. However, it was not discussed in connection with the robotics-specific knowledge and practice. A collaborative attitude can be different depending on the required robotics-specified knowledge in an educational context. Therefore, the attitude domain of robotics education needs to be developed more specifically in connection with robotics knowledge and practice.

3.2. Key Research Trends about Young Children's Robotics Learning

What parts of young children's robotics learning did the existing studies focus on? What did the studies address about those parts? Here, we share our analysis of key topics that the reviewed studies aimed to examine. We thematically categorized the key findings into six themes.

3.2.1. Effects of Robotics Education on Young Children's Learning

Our review showed that more than half of the reviewed studies (63.8%) have focused on the benefits of robotics education for young children. This line of study was interested in what advantages young children could gain through engaging in robotics activities such as constructing and programming robots. We identified two points that the 30 studies stressed in carrying out outcome-focused studies.

First, the prior studies mainly showed specifically what kinds of knowledge, skills, and attitudes young children achieved. It was noticed that the achievements were reported in a way that connected them to knowledge and skills of different subject areas (e.g., numeracy, scientific inquiry skills, and literacy) [20–25]. For instance, from a micro-ethnographic case study approach, McDonald and Howell's study showed that a robotics project positively impacted five- and seven-year-old children's literacy development and numeracy skills [22]. While engaging in robotics activities, the young children expanded their terminology and employed more complex sentence structures to explain robots' behaviors or explain their ideas. Julià and Antolí compared 6th graders who participated in a 10-week robotics course with ones who did not join the course [47]. Their study showed that the participating children developed statistically more advanced spatial abilities than non-participating children. With quantitative and qualitative data, the pilot study of Eck and colleagues demonstrated that robotics activities had an influence on kindergarten children's performance of the executive functions [48]. The results meant that kindergarteners improved their endurance and ability to concentrate over a certain period along with developing planning and cognitive flexibility to apply to learned abstract rules.

The second point was centered on the participant learners' ages. The studies paid attention to the extent to which young children—including preschool and kindergarten children—were able to learn [31,49–56]. Bers and her colleagues are key scholars in this area. For example, Bers, Flannery, Kazakoff, and Sullivan presented quantitative evidence that kindergarten children were able to learn higher levels of computational thinking (e.g., looping and numeric parameters) [50]. In particular, this study specified the level of computational thinking (looping with numeric parameters vs. conditional statements with sensor parameters) to compare the children's achievements. Their results highlighted that even kindergarten children were able to understand and perform looping and numeric parameters; yet, they needed more adult support and time to learn conditional statements and sensor parameters.

In addition, a recent study by Sullivan and Bers quantitatively compared the achievements of three different age groups of children (pre-K, K, 2nd) in the following two different knowledge aspects [49]: (1) robotics knowledge (e.g., different parts of the robot and their functions); and (2) programming knowledge (e.g., easy sequencing, hard sequencing, easy repeat loops with number parameters, advanced repeat loops with number parameters, easy sequencing with the different conditional commands, easy repeat loops with sensor parameters, hard repeat loops with sensor parameters, and conditional branching). Interestingly, the results of this study showed that all ages of children performed equally well even on the advanced programming tasks. However, they reported that young children (pre-K) needed to learn at a slower pace, with repetitive experiences, and with one-on-one adult assistance.

Given that young children were rarely represented among learners in the STEM area, we suggest that outcome-focused studies can contribute to raising expectations of young children's intellectual capabilities [1]. In addition, the literature can be helpful in clarifying developmentally appropriate expectations for robotics learning by providing additional data. However, the outcome-focused literature can be seen as biased towards highlighting the advantages of robotics education more than the needs of young children to learn robotics.

In addition, one noticeable commonality was that the 30 studies commonly reported young children's intrapersonal and interpersonal attitudes. Although those areas were not the main targeted topics of the studies, the research mentioned those effects as unexpected but very impressive findings [20,22,23,43,57,58]. We also agree that those areas of findings were very significant in that the children's expanded intrapersonal and interpersonal attitudes were the core dimension of the children's holistic development. In early childhood education, the holistic approach has been valued as a means of integrating children's academic learning with their social and emotional development [59]. The holistic view suggests that children can connect academic learning with authentic social practices through experiencing strong relationships with peers and adults in their learning community. [60]. Not only early childhood education but also STEM disciplines and contemporary society expect children to accomplish holistic development through education [61]. However, despite the significance, the majority of studies of robotics education still place more emphasis on cognitive and skill domains than the attitude domain.

3.2.2. Young Children's Conceptualization of Robots and Systems of Robots

Compared to other types of educational technology and movable toys, educational robots have distinct functions. Robots appear to have human-like features; at the same time, robots' animated behaviors are controlled by engineering and mechanical rules-based systems [9,62]. While noticing the robots' distinct features—the tangible hardware and invisible software (a rule-based autonomous system)—some studies assumed that reasoning about robots' behaviors and systems are significant aspects of technological literacy [63]. For this reason, by zooming in on young children's encounters with robots, these studies started with questions about what kinds of perspectives young children had for reasoning about the robots' systems or in what ways young children conceptualized robots' rules-based systems.

Five studies among the 47 reviewed focused on this aspect of robotics [37,64–67] Commonly, the studies investigated how young children developed their conceptions of robots' behaviors and systems of robots.

In the study by Mioduser and Kuperman [37], kindergarten children participated in constructing and programming robots. Noticeably, this study identified the engineering perspective (i.e., children use technological language) and the psychological perspective (i.e., children use anthropomorphic language to describe robots' behaviors) as a frame to analyze children's verbal statements. The findings of this study showed that kindergarten children's language mostly reflected the engineering perspective. However, during story-based tasks or under natural situations such as conversations with robots, young children tended to use anthropomorphic language (e.g., describing robots' behaviors as human-like intentions and emotions) more than the technological language. This study showed that young children's anthropomorphic perspectives changed into technological perspectives. Ultimately, the authors claimed that kindergarten children's perceptual focus on robots' behaviors evolved from observing robots' behaviors into understanding causes of the behaviors.

Before carrying out the above study, Levy and Mioduser conducted a study which had a similar topic and setting but different findings [67]. This study also captured five- and six-year-old children's different perspectives (the engineering and the psychological perspectives). In this study, the authors presented two interesting points. First, while engaging in constructing and programming tasks, participant children conceptualized self-regulated robots in a "bridging mode"—referring to the tendency to combine two different technological and psychological frameworks. Second, the difficulty of the tasks influenced the children's frameworks. For example, through concrete vignettes, this study showed that the children used technological perspectives in the easiest tasks (e.g., one condition and one action); however, the more difficult the tasks became, the more the children's technological perspectives transitioned into psychological perspectives.

Here, we suggest that this line of study is worth noticing in that it firstly valued young children's stance toward robots. Robotics activities are a kind of purposeful setting that includes a broad scope of cross-domain knowledge and skills. However, from a young child's points of view, a robotics activity may first be an encounter with an unfamiliar type of behaving artifact before it becomes a learning activity [68]. Thus, we think these studies conducted to understand children's reasoning and their own frameworks should be the foundation of research in robotics education.

In addition, another strong point that this line of study contributes is to suggest different theoretical frameworks to understand young children's distinct tendencies. For example, these studies appreciated young children's distinct perspectives (such as a bridging mode or switching between anthropomorphic and technological frameworks) as a more mature cybernetic view [62], not a lack of rational thinking ability.

3.2.3. Young Children's Processes and Strategies for Learning Robotics

Relying on constructivism [69] and constructionism [70], the process-oriented activity and the sensory-engaged process have been the most often cited advantages of robotics education. However, we noticed that relatively few studies (three) aimed to investigate the nature or characteristics of young children's robotics learning process [22,38,71].

While observing kindergarten children engaging in programming tasks, Levy and Mioduser found two important modes, which they termed participatory investigations and anticipatory constructions [38]. In this study, young children tended to enjoy direct bodily interactions with the robots when they were in the process of programming tasks. The authors argued that playful bodily engagement allowed children to directly experience the simulated system; thus, this first mode functioned as an effective strategy to understand programming. In addition, the children presented anticipatory construction strategies. While interacting with the robots, they tended to envision how the robots would move in advance. The author interpreted that this strategy supported the idea that children should plan for completing programming tasks before arbitrarily programming the robots.

Yuen and colleagues examined elementary school children's (3rd to 5th graders) collaborative process in a summer robotics camp [71]. The quantitative results provided three specific insights about the collaborative nature of robotics learning. First, this study presented that there was no significant correlation between building robots and group interactions; thus, this finding implied that building robots was not part of the children's collaborative process; instead, they preferred having individual or off-task times for building and programming. Second, while waiting for their turns, the children were not only able to wait patiently but also used the waiting time for observing others. The authors claimed that observing other group members positively impacted children's ultimate decision-making for completing tasks. Lastly, the study stressed that the competition-based approach was effective in motivating the children to complete group tasks because the approach enabled the children to have a strong sense of teamwork.

Overall, we conclude that the children's process-focused studies were very practical in that the findings can suggest more responsive and accessible pedagogical implications for teaching young children. Because the process-focused studies shared detailed processes of children's robotics learning, the process-focused studies can shed light on authentic aspects of robotics education. In addition, they can provide pedagogical implications relevant to young children's unique interests, tendencies, and needs. However, our review revealed that an insufficient number of studies demonstrated the processes of young children's robotics learning. There was also little concern with children's perspectives and modes of approaching robotics learning.

3.2.4. Assessment of Young Children's Robotics Learning

Savard and Freiman started their study by pointing out that assessments of children's robotics learning were intrinsically very complicated because children's performances in completing tasks involved different contexts [72]. The authors evaluated and analyzed how 5th and 6th grade children performed robot-tasks by using three different contexts (mathematical, digital, and socio-cultural). Their analysis indicated that children's performances were different depending on: (1) what kinds of feedback—among feedback from mathematical, digital, or socio-cultural contexts—the children recognized; and (2) how they interpreted the feedback and applied it to their tasks.

Even though this study focused on the assessment aspect of robotics education, we think this study addressed more than merely assessment. This study argued that success or failure in performing tasks cannot be sufficient criteria. Rather, it suggested that the associative perspective—considering both "what kinds of concepts and skills the children used" and "in which contexts they used them" together—was needed. This argument called our attention to the importance of context for understanding children's robotics learning. We agree with the authors' associative perspective on children's robotics learning. The fact that children employed robotics materials and successfully performed tasks was important; however, we think that it was only a part of the children's learning. Therefore, we suggest that the associative perspective needs to be applied to other research agenda.

3.2.5. Gender Differences in Robotics Learning

Surprisingly, there is only one study concerned with different aspects of learners [35]. Sullivan and Bers were concerned with the gender differences in kindergarten children's robotics learning [35]. Their quantitative results indicated that boys had a higher mean score than girls on more than half of the tasks; however, very few of these differences were statistically significant. Therefore, the authors claimed that both girls and boys were able to have successful learning experiences, in particular when they were exposed to robotics and programming as early as kindergarten.

This study was a good beginning to bring important issues to the surface and to refute gender stereotypes in STEM learning. On the other hand, it can be a limitation that this study considered the children's gender just as a biological distinction (boys versus girls). Gender is presented as basic demographic information in the reviewed research. However, we suggest that further explanations of gender (e.g., boys' and girls' gendered behavioral patterns and explicit/implicit social and cultural contexts of the behavior) are needed. We suggest that adequate theoretical frameworks should be added in this line of literature. Given the masculine image of STEM professions and misconceptions about the achievement gap between girls and boys, gender should be viewed as a socially constructed matter [73–75]. For example, the notion of Butler's gender performativity can guide research to understand girls' engagement in robotics education as gender performance to construct their gender subjectivity [76]. Feminist theory can help view educational robotics as resources or texts that have discursive and ideological voices, and to identify what gender discourses young children have encountered and negotiated through their engagements with robotics kits [77,78].

Overall, very little research has been done to investigate young children's robotics learning in connection with the different features of the learners. Considering the increasing numbers of non-mainstream students and calls for equity in STEM, young children's race, culture, ethnicity, languages, socioeconomic class, and different prior experiences need to be addressed. In addition, to conduct studies on learners' different characteristics, different perspectives, such as sociocultural perspectives, and theories are necessary.

3.2.6. Factors and Conditions of Robotics Learning

Lastly, seven studies focused on different factors and conditions that played out in young children's robotics learning [10,53,79–83]. Specifically, Elkin, Sullivan, and Bers paid attention to the characteristics of the Montessori early education classroom [79]. The study revealed that teachers' comfort with robotics kits and robotics contents, and the Montessori educational philosophy (students' freedom to explore their personal interests, developmentally appropriate material, and minimal interventions from teachers) increased the potential for integrating robotics into educational settings.

In another study, Strawhacker and Bers compared three different robotics interface conditions (tangible interface vs. graphical interface vs. hybrid interface) [53]. As a mixed method approach, the authors numerically showed that the types of interfaces used had little influence on kindergarten children's programming comprehension. However, importantly, this study demonstrated that the order in which different interfaces were introduced affected children's learning of programming. The authors argued that teaching programming with a single interface first was better than two at once. Interestingly, the authors pointed out their limitations in capturing what factors made a difference in children's learning of programming. Thus, they suggested that the effect of different interfaces should be investigated in a collective way. Simply put, this study showed the necessity of further study to determine what specific processes, perspectives, and learning patterns would affect children's learning of programming.

Liu and her colleague analyzed teachers' interaction patterns with preschool children [80]. They demonstrated that teachers' questions were crucial to support the children in reflecting on problems and identifying solutions. Relying on their empirical data, they argued that young children required teachers' one-to-one support to learn programing. Janak's study paid attention to the attractiveness and the age-appropriateness of Bee-Bots [82]. This study found out that the Bee-Bot's attractiveness did not sustain the preschool children's motivation and attention for a long time. Rather, the story-based approach with Bee-Bots helped the children engage in robotics learning. Thus, Janak emphasized that the robotics kit itself cannot guarantee meaningful experiences for young children.

Even though seven of the 47 studies directly dealt with conditions or factors involved in children's robotics learning as a research topic, the remaining studies briefly mentioned them as well. Usually, while interpreting their findings and discussing implications, the studies took the following factors or conditions somewhat into account. We summarized the factors investigated or mentioned in the reviewed studies in Table 2.

Regardless of the degree of depth to which they were addressed, we identified that a common message of the reviewed studies was the fact that whatever factors were investigated in the research, a single factor was not sufficient to understand young children's robotics learning. Therefore, it can be said that different factors and conditions involved in children's robotics learning process should be understood in collective and interconnected ways.

Meanwhile, as Table 2 shows, the focus of the literature is directed toward factors of robotics curricula (e.g., teaching approach, teachers' questioning, technological features of tools, and order of activities). Except for curriculum or instructional factors, learners' age was the most frequently considered. This is because the research has been lowering the target age to include pre-K and K. However, here we point to the fact that learners' age is a single characteristic that the children hold. Existing literature has tended to magnify the age factor in different ways from situated classroom contexts or learners' larger contexts (community, social, or cultural contexts).

Table 2. Factors Involved in Children's Robotics Learning.

Themes of Factors	
Teaching Approaches Applied in Robotics Education	• Narrative (Story)-based approach • Collaborative approach • Hands-on approach • Problem-solving approach • Trial-and-error method • Exploratory learning approach • Inquiry-based approach • Project-based approach • Free-play based approach
Technological Features of Robotics Kits	• Types of feedbacks • Playfulness • Age-appropriateness
Adults' Support	• Types of supports • The degree of adults' support • Characteristics of adults' support
Characteristics of Learners	• Age • Gender • Ability
Classroom Conditions	• Formal school setting vs laboratory setting • Flexible time schedules

3.3. Theoretical and Methodological Features

To answer the third question of this study—about theoretical and methodological features of the existing research—we analyzed theoretical and methodological aspects of the 47 studies (see Appendix).

3.3.1. Dominant Theoretical Frameworks

The reviewed studies employed two dominant theoretical frameworks: (1) Piaget's constructivism [69]; and (2) Papert's constructionism [70]. Considering the overall patterns of use of these two frameworks in the literature, we first noted that these two frameworks functioned as the foundation of the rationale of robotics education. For example, relying on constructionism, the tangibility of and functional properties of robotics kits are frequently mentioned to address the appropriateness of robotics education for young children [4,31,50–52,79]. In addition, the reviewed research that used a constructivism framework presented their robotics education programs and curricula as providing young children with experiential opportunities to be active knowledge-constructors [20,55,64,84].

However, we think it is necessary to distinguish theoretical frameworks for designing and implementing robotics curricula from theoretical frameworks for research. We acknowledge that those frameworks were useful in providing thick information about robotics curricula, teaching methods, and learning environments, and thus contributed to building solid pedagogical foundations for the studies [27]. However, the existing studies relying on the frameworks provided relatively simple descriptions or shallow interpretations of the children's engagement in robotics education. Savard and Freiman suggested that children's robotics learning should be investigated from different perspectives that can capture children's complicated and collective processes [72]. While acknowledging difficulties in examining the details of the children's learning process, Strawhacker and Bers expressed the need for alternative views to provide in-depth qualitative descriptions [53].

In addition, we noticed that the problem here was that the studies narrowed down constructivism and constructionism into a technological determinist paradigm. We do not intend to problematize constructivist and constructionist frames to understand young children's engagement in robotics education; rather, our point is to argue that the ways the existing literature used those frames were limited by technological determinism. Technological determinism refers to the claim that "technology itself exercises causal influence on social practice" [85] (p. 338). In a teaching and learning context, the determinist paradigm views robotics kits as shaping children's learning. This paradigm attributed the main cause of learning outcomes to the robotics technologies.

However, we think that this kind of determinism tends to simplify the interaction between young children and robotics kits as unidirectional and decontextualized, rather than bidirectional/multidirectional and context-specific. The determinist belief has magnified and essentialized the prescribed functions and effects of robotics kits. Using experimental research designs, the attention of previous studies was narrowed to the restrictive nature of category-based analysis [86]. Such analysis selectively focused on the expected results of young children's engagement with robotics kits rather than processes or unanticipated results. Furthermore, in such analysis, the intentions and values of robotics program designers and robotic technology developers were the primary considerations. In this sense, it is necessary to take an alternative approach to understand young children's engagement with educational robotics and their participation in robotics education from social, cultural, political, and historical perspectives.

3.3.2. Research Design and Data Collection

In a review study, Alimisis called for validation of the impact of robotics education though a more quantitative approach [87]. However, the studies we reviewed had rigorous research designs based on qualitative data of student achievements. In addition, reviewed studies were conducted with qualitative, quantitative, and mixed approaches in almost equal proportions (see Appendix).

The majority of reviewed studies established an experimental design. These studies tended to see a causal relationship between implemented robotics curricula (cause) and children's outcomes (effect). For this, the studies controlled robotics learning situations and compared experimental groups with control groups. Along with the outcome-focused research, this research design trend leads to systemic and rigorous evaluation to prove the impact of robotics education.

On the other hand, the experimental design has a controlled and manipulative nature [88]. Consequently, the studies simplified the children's learning process and omitted indirect factors involved in the process. In addition, the research settings were artificial (e.g., laboratory settings, a science event day, a special workshop) and were detached from regular classroom contexts. Recently, however, there has been an emerging interest in integrating robotics with regular curricula in schools, and there is now growing attention paid to the connection between children's ordinary lives and robotics education [19,89–91].

In regard to methods, the studies attempted to collect data rigorously by using standardized evaluation tools and/or by doing participant observations. However, we point out the fact that the collected data relied mainly on children's verbal descriptions and performance achievements. Of course, this type of data clearly and effectively supported the studies' hypotheses. However, we should remember that young children tend to interact with their environments through different forms of communication (such as bodily movements, gestures, facial expressions, and drawings) [92,93]. In addition, given that the robotics learning process is basically a tangible interaction with robotics kits and technological environments, different forms of data should be recognized. Doing so would provide more detailed and in-depth information to understand children's engagement in robotics.

4. Conclusions

Based on our review findings and the above discussion, we suggest the following. First, we suggest developing and enhancing the robotics-intensified knowledge, skill, and attitude domains for robotics education. In particular, considering that robotics is a part of computer science, robotics education is often positioned only in the context of STEM disciplines. Kay argued that teaching robotics needs to include the computer science perspective as a way of balancing of robotics theory and the practical challenges of building and programming robots [94]. Considering that the studies we reviewed tended to stress the practical experiences of robotics education (e.g., building and programming robots to solve a problem), it is worth listening to Kay. Including the perspective of computer science education can contribute to the knowledge young children need to gain about robotics and how to apply it in practice. In addition, collaboration with the computer science education community can be vital to support robotics education by outlining the core concepts (e.g., algorithmic and artificial intelligence) and practices (e.g., hardware and software design) of robotics [95]. It will help to establish scopes, contents to learn, and levels of difficulties of robotics education; thus. robotics learning need not be constrained by the types of robotics kits available for the children to use.

Second, we suggest shifting the focus of robotics education research from robotics technology and its effects to young children themselves. Arguing for a shift in focus from technology to pedagogy, Alimisis stated that the fundamental issues of robotics education need to be educational theories, the curricula, teaching methods, and teaching philosophies, not the robotics technology itself [27]. In the same vein, we also argue that types of robotics kits, pedagogy, and young children all need equal attention in educational robotics research [9]. In particular, we suggest paying close attention not only to the physical properties of robotics kits and the effects of robotics curricula, but also to the young learners and how they learn. Instead of positioning young children as adopters of robotics technology, we need to appreciate and investigate young children's agency to adapt robotics technology and make changes in their engagement with the technology [94].

Third, we suggest that research agendas move beyond the outcome-focused trend. Research topics need to be diversified to investigate young children's engagement processes in robotics activities. While previous studies supported robotics education as an appropriate and meaningful learning opportunity for young children, they did not explain in which ways robotics education facilitates young children's meaning construction nor which aspects of robotics-learning experiences can support them [96]. Meanwhile, when researchers attempt to examine young children's learning processes in robotics education, they should first listen to the participating children's voices. Investigating young children's learning processes can be a way to identify the children's learning trajectories and make sense of their experiences in robotics education. By capturing children's engagement processes in robotics education, their dynamic and complicated interactions with robotics kits, teachers, and peers can tell us how robotics education can be connected to their distinct perspectives, particular interests, needs, and situated contexts [97]. Finally, understanding young children's learning processes can be grounds for feasible pedagogical implications for different learners who have diverse backgrounds.

From a critical perspective on educational technology, we suggest that alternative perspectives are needed to understand young children's engagement with educational robotics and their participation in robotics education. In particular, we suggest social and cultural frameworks for the educational uses of robotics. For example, Oliver identified the following social and cultural theories to frame the relationship between technology and learning as examples of alternative frames [98]: Cultural Historical Activity Theory (CHAT) [99], communities of practice [100], and Actor-Network-Theory (ANT) [101]. We think that social and cultural theories can help investigate the social, cultural, institutional, and political contexts involved in robotics education [102]. Furthermore, these frameworks can support identification of the ways young children alter, change, and intervene in the circumstances of robotics education and the ideologically-driven meanings of robotics kits [103]. They can reveal how young children make personal, social, and cultural meanings from robotics kits and in what ways young children interact with the robotics kits beyond prescribed and expected actions.

We recognize some limitations of this study. First, our decision to focus on literature using robotics kits did not represent the entire literature on robotics education for young children. Had our review considered studies that employed social robots, our results might have been different. Second, we considered the ages of participant children but did not consider other characteristics, such as their academic performance. Further review research may consider the relationship between students' academic performance and their ways of engagement, along with different types of educational robots.

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Appendix

#	Author	Year	Age	Robotics Kits	Research Approach	Theoretical Framework
1	Cho, Lee, Cherniak, and Jung [104]	2017	8	• BeeBot • Cubelets	Qualitative research Case study	• Actor-Network Theory
2	Di Leito, Inguaggiato, Castro, Cecchim Ciono, Dell'Omo, and Dario [105]	2017	5–6	• BeeBot	Quantitative research Experiential study	-
3	Kopcha, McGregor, Shin, Qian, Choi, Hill, and Choi [42]	2017	10	• Robots can be constructed and programmed	Qualitative research Educational Design Research	-
4	Sullivan, Bers and Mihm [31]	2017	4–7	• KIBO	Mixed Methodology Exploratory study	• Constructivism • Constructionism
5	Savard and Freiman [72]	2016	10–11	• Lego Mindstorms	Qualitative research Evaluative study	• Socio-cultural perspective of learning • Ethno-mathematical model
7	Sullivan and Bers [49]	2016	4–7	• KIWI	Quantitative research Comparison study (Age)	-
8	Bennie, Corbett, and Palo [43]	2015	8–11	• LEGO NXT • WeDo LEGO kits	Qualitative research	• Engineering design process • Five C skills: communication, collaboration, critical thinking, cooperation, creative problem solving
9	Gordon, Rivera, Ackermann, and Breazeal [106]	2015	4–6	• Social Robot (SoRo) Toolkit and Vinyl icon stickers	Qualitative research Experiment Study	-
10	Julià and Antolí [47]	2015	11(6th grade)	• Universal 3 • ROBO LT Beginner Lab • Oeco Tech	Quantitative research Experiential study	-
11	Somyürek [52]	2015	8 and 14	• LEGO Mindstorms • NXT construction kits	Experimental study	• Constructivism
12	Spektor-Precel and Mioduser [64]	2015	5 and 7	• RoboGan • LEGO kits • Modifiable landscapes	Mixed Methodology	• Theory of Mind • Theory of Artificial Mind

#	Author	Year	Age	Robotics Kits	Research Approach	Theoretical Framework
13	Strawhacker and Bers [53]	2015	5–6	• LEGO WeDo • CHERP (the Creative Hybrid Environment for Robotic Programming)	Mixed Methodology Comparison study (Three different types of interfaces)	• Constructivism • Positive Technological Development
14	Zaharija, Mladenović, and Boljat [57]	2015	7–8	• Lego Mindstorms	Quantitative research Experimental study	-
15	Eck, Hirschmugl-gaisch, Kandlhofer, and Steinbauer [44]	2014	5	• Bee-Bots • Cubelets • Lego Mindstorms NXT	Qualitative research Empirical evaluative study	-
16	Bers, Flannery, Kazakoff, and Sullivan [50]	2014	4.9–6.5	• CHERP TangibleK Robotics	Quantitative research Evaluative study	• Constructionism • Positive Technological Development
17	Cacco and Moro [20]	2014	6	• Bee-Bot	Mixed Methodology Design-based research Experimental study	• Papertian Perspective • Constructionism
18	Elkin, Sullivan, and Bers [79]	2014	6–8	• Lego WeDo	Mixed Methodology A case study	• Constructivism
19	Hwang and Wu [58]	2014	6	• MSN system • Multi-robots	Mixed Methodology Experimental study	-
20	Kazakof and Bers [51]	2014	4.5–6.5	• CHERP • Lego Mindstorms	Quantitative research Experimental study	• Constructivism
21	Yuen et al. [71]	2014	8–10	• LEGO Mindstorms • NXT Robotics Kit	Quantitative research	-
22	Datteri, Zecca, Laudisa, and Castiglioni [21]	2013	7	• LEGO Mindstorms	Qualitative research Ethnographic approach	-
23	Eck et al. [48]	2013	4–5	• Bee-Bots • Cubelets • Lego Mindstorms NXT	Mixed Methodology Experimental study	-
24	Kazakoff, Sullivan,and Bers [55]	2013	5	• CHERP • LEGO® Education WeDo	Quantitative research Comparison study	• Constructivism • Constructionism

#	Author	Year	Age	Robotics Kits	Research Approach	Theoretical Framework
25	Liu et al. [80]	2013	5	• Topobo • (programmable bricks)	Exploratory case study	-
26	Ma and Williams [45]	2013	8–10	• Lego-based robots • (building and programming)	Qualitative research A case study	-
27	Sullivan and Bers [35]	2013	5–8	• CHERP • LEGO MINDSTORMSTM kit	Quantitative research Experimental study	-
28	Sullivan, Kazakoff, and Bers [54]	2013	5	• CHERP • LEGO® Education WeDo	Qualitative research Experimental study	• Piagetian theory • Vygotsky's ZPD • Positive Technological Development Framework (PTD)
29	Kazakoff and Bers [56]	2012	4.5–6.5	• CHERP • LEGO® Education WeDo	Quantitative research Comparison study	-
30	Kwon, Kim, Shim, and Lee [81]	2012	6	• Bricks (Algorithmic Bricks)	Quantitative research Comparison study	-
31	McDonald and Howell [22]	2012	5–7	• LEGO® Education WeDo	Qualitative research Ethnographic case study	-
32	Mioduser and Kuperman [37]	2012	5.4–6.3	• Robogan • (A dedicated iconic interface) • LEGO	Qualitative research Experimental study	-
33	Slangen, Van Keulen, and Gravemeijer [65]	2011	10–12	• Lego Mindstorms NXT robots	Qualitative researchExperimental study	• Conceptual frameworks for robotics
34	Stoeckelmayr, Tesar, and Hofmann [84]	2011	5–6	• Bee-Bots	Qualitative researchExperimental study	• Developmental Psychology • Constructionism
35	Wei, Hung, Lee, and Chen [23]	2011	7	• Robot learning companion (sensing input devices, mobile computation unit, mobile display devices, and wireless local network) • Lego Mindstorms NXT robots	Quantitative research Experimental study	• The experimental learning theory Constructivism • Joyful learning theory

#	Author	Year	Age	Robotics Kits	Research Approach	Theoretical Framework
36	Highfield [24]	2010	6 and 8–9	• Bee-Bot • Pro-Bots	Qualitative research Case study	• Constructionism
37	Jojoa, Bravo, and Cortés [107]	2010	6–12	• Lego Mindstorms NXT robots	Qualitative research Case study	• Constructionism • Constructionism • Vygotsky's ZPD
38	Levy and Mioduser [38]	2010	5–6	• RoboGan	Mixed Methodology Exploratory study	• Cognitive psychology • Constructionism
39	Mioduser and Levy [39]	2010	5	• RoboGan	Mixed Methodology Exploratory study	• Cybernetic Theory
40	Ruiz-del-Solar [108]	2010	11–13 (6th grade)	• BEAM robotics • LEGO Mindstorms set	Qualitative research Case study	-
41	Mioduser, Levy, and Talis [66]	2009	K	• LEGO • Landscapes • Computer interfaces	Mixed Methodology Exploratory study	• Situated Learning • Vygotsky's ZDP
42	Chambers, Carbonaro, and Murray [25]	2008	9–10	• LEGO Mindstorms set	Qualitative research Case study	• Constructivist learning theory • Constructionism
43	Janka [82]	2008	4	• Bee-Bots	Qualitative research Case study	• Constructivism • Constructionism
44	Levy and Mioduser [67]	2008	5–6	• LEGO • Landscapes • Computer interfaces	Qualitative research Case study	• Vygotsky's ZDP
45	Bers [109]	2007	4–7	• LEGO Mindstorms set • ROBOLABTM (programming language)	Mixed Methodology Design-based research	• Constructivism • Legitimate Peripheral Participation
46	Beals and Bers [83]	2006	6–7	• LEGO Mindstorms set • ROBOLAP software	Mixed Methodology Exploratory study	• Constructionism • Vygotsky's ZDP
47	Hussain, Lindh, and Shukur [110]	2006	12–13 (5th grade)	• LEGO Dacta	Mixed Methodology Exploratory study	• Constructivism • Theory of situated cognition

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