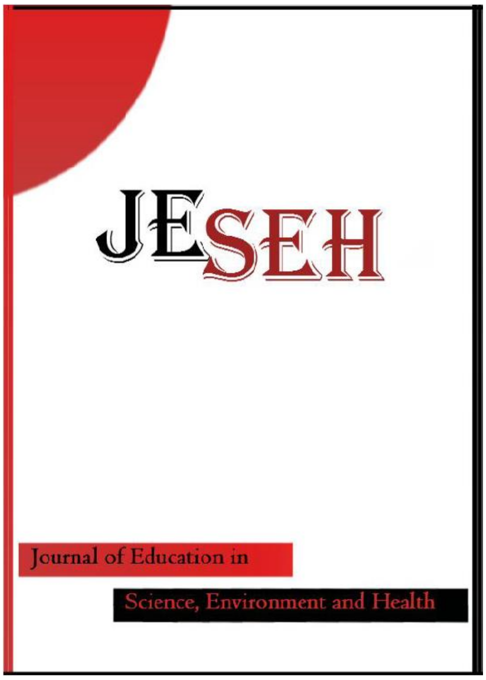

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Studies on Robotic Coding Education in Science Education: A Systematic Literature Review

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Studies on Robotic Coding Education in Science Education: A Systematic Literature Review

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Abstract

This study aims to examine the methodological trends and findings in studies on robotic coding in science education published between 2015-2022 comprehensively and holistically. For this purpose, the articles related to the subject were systematically reviewed. In addition, web of Science and SCOPUS databases were scanned for keywords related to robotic coding, and 15 studies on robotic coding with full-text access were included in the analysis. The researchers prepared a data collection form to analyze the publications included in the research within the framework of the determined categories. Regarding the results of the review of robotic coding studies in science education, they mainly focus on cognitive skills, followed by applied studies in robotic coding teaching. The suggestions for future robotic coding studies in science education mainly involve applications and further research. Regarding applications, there are more suggestions for the integration of robotic coding. In this context, it was recommended to carry out studies that examine various 21st-century skills, integrate different disciplines, use different equipment, address psychomotor skills, and focus on curriculum development.

Introduction

The widespread use of technology in the world has led to developments in many areas. For example, communication technologies such as tablets, phones, and computers are widely used in homes, workplaces, schools, and social life. Computers used in workplaces, robot vacuums used at home, and self-parking vehicles are examples of technologies used in daily life.

Individuals of the 21st century have access to vast amounts of information and live in a technology- and media-driven environment. For this reason, there is a need for the use of technology in education and the integration of innovative, developing, and widely used technologies into lessons. For example, augmented reality, virtual reality, mixed reality, mobile applications, simulation, social networks (Facebook, Instagram, etc.), educational and digital games, digital storytelling, artificial intelligence, QR code applications, and 3D printing (Adams Becker et al. 2016; Johnson et al., 2015), metaverse and robotic technologies are developing technologies that are frequently used in education.

New educational approaches and models have emerged with the increasing use of technology in education. One of these models is robotic coding, which is on the agenda as a sub-dimension of STEM (Science, Technology, Engineering, and Mathematics) (Reader, 2019). Parents and educators have recently started to concentrate on the missing "T" of technology and the "E" of engineering in STEM programs thanks to the development of new technologies, curricula, and national efforts (Bers et al., 2013). Therefore, it can be said that providing robotics and coding training with a STEM approach will make it easier to reach 21st-century skills.

Individuals need 21st-century skills to adapt to the changing world. However, different institutions, organizations, and authors classify 21st-century skills differently (Partnership for 21st Century Skills[P21], 2010; Trilling & Fadel, 2012; Wagner, 2008). For example, P21 classifies 21st-century skills as learning and innovation skills, career and life skills, and information, media, and technology skills. Trilling & Fadel (2012) address 21st-century skills in three sub-titles: learning and innovation, digital literacy, and career and life skills. Wagner (2008), on the other hand, discusses 21st-century skills under seven headings, taking the initiative, entrepreneurship, adaptability, leadership, cooperation, problem-solving, critical thinking, imagination, access to information, and communication. These skills overlap with the skills required for coding (technology literacy, communication, problem-solving, scientific creativity, cognitive process skills, etc.).

The concepts of coding and programming began to be used in education in the 1960s. As a result, coding and programming are used interchangeably in the sources. However, it should be noted that programming is a broad concept that includes coding. Moreover, the interest in coding, which has emerged as a requirement of the digital world, is increasing. In general, coding emerges as describing the tasks we want a computer, machine, or system to do in an appropriate language. Coding is the entirety or a portion of a series of instructions written for a computer, electronic circuit, or mechanical device to carry out an action or accomplish a certain goal (Guven et al., 2022). In other words, coding is writing a block-based computer program by setting up various algorithms using a software language (Reader, 2019). Coding can be done with or without a computer. In computerized coding, tablets and smartphones can be used instead of computers.

Garcia-Pealvo et al. (2016) claim that teaching kids how to code enhances their capacity to use technology, helps them learn, and gets them ready for a variety of life situations. The ability to code is acknowledged as being vital for the growth of computational thinking, teamwork, communication, and creative problem-solving skills (Bocconi et al., 2016). Bers (2008) sees coding as a way to achieve literacy in the 21st century, just like reading and writing.

Although the discussions about coding started in the USA, they have rapidly spread to other countries (Aydeniz & Bilican, 2018). Coding education did not stay only at the K12 level (preschool, primary and secondary education) but also took place in undergraduate and graduate education. Many countries (USA, Australia, Brazil, Europe, etc.) have included coding education in their curriculum to improve children's computer programming and coding skills (Aydeniz & Bilican, 2018). Coding education efforts took place nationally and locally in these countries (USA, Australia, Brazil, Europe, etc.). In Turkey, the Ministry of National Education has decided to gradually add a course called "Information Technologies and Software" to the curriculum starting from the fifth grade in the 2012-2013 academic year (Sayın & Seferoğlu 2016). There are different organizations and different practices related to coding. Organizations such as Code Academy, Code Club, Khan Academy, Coder Dojo, and Code.org continue their efforts to teach coding in the programming field. Programming tools such as Microsoft Small Basic, Alice, MIT App Inventor, and Scratch are also available for individuals who have just started programming (Demirer & Sak, 2016).

Another concept that comes up with coding is robotics. Robots are functional tools that can be programmed to perform a task. Robots can sense the environment through sensors; the data obtained from sensors are interpreted, and various reactions are produced as programmed by the microcontroller or processor (Guven et al., 2022). Robots are controllable and programmable technological devices with sensors consisting of electronic and mechanical parts (Arora, 2008). The use of robots has become widespread not only in engineering but also in education (Yolcu & Demirer, 2017; Papert, 1980). On the other hand, robotic coding is defined as block-based programming to control and direct the movements of a robot created for various purposes (Reader, 2019).

The number of studies (articles, web pages, and various materials) on using robots in education is increasing. The studies on the educational use of robots stated that robots contribute positively to students' problem-solving skills (Robinson, 2005; Rogers & Portsmore, 2004). In addition, educational robotics applications attract the attention of students (Prensky, 2008), increase their learning motivation (Bazylev et al., 2014; Robinson, 2005; Rogers & Portsmore, 2004), improve their self-efficacy (Psycharis & Kallia, 2017), creative, critical, computational thinking skills (Catlin, 2012; Czerkawski & Lyman, 2015) and contribute positively to their learning in cognitive, affective, social and moral development areas (Lau & Yuen, 2011; Wei et al., 2011).

By combining robots and cutting-edge technological applications in the classroom, the studies in the subject of robotics education seek to give teachers a robotics curriculum that is connected with science and technology and to make learning more significant and lasting (Wood, 2003). The widespread interest in robotics has grown surprisingly over the past few years. Robotics is seen by many as a means of providing critical new benefits at all levels of education (Johnson, 2003). Robots used in education seem to be suitable tools to improve learning. However, more empirical studies are needed to test their benefit (Benitti, 2012).

The WOS database was used for the systematic review of coding education in science education. The database was scanned using robotic coding and systematic analysis as keywords, and 18 studies have been found. However, only four of these studies were conducted in the field of education (Ezeamuzie, 2022; Sun & Zhou, 2022; Taslibeyaz, 2020; Wang et al., 2021). Furthermore, one of these studies was a meta-analysis (Sun & Zhou, 2022). This situation shows a need for more systematic reviews on coding education in science education. This study is important because it synthesizes the studies conducted between 2015-2022 on robotic coding education in science education.

This study is valuable for determining the trends in robotic coding education in science education. It aims to determine the trends of the studies conducted between 2015-2022 on robotic coding in science education. In addition, this study interprets and outlines research on robotic coding in science education.

Method

This study was designed as a systematic literature review (SLR) on robotic coding in science education. The systematic review is a method mainly developed to synthesize research findings in medicine systematically, transparently, and reproducibly (Davis et al., 2014).

A systematic review can be described as a research method and process for collecting and analyzing data from research and identifying and critically evaluating the relevant ones (Liberati et al., 2009). It aims to reveal all empirical evidence that meets predetermined inclusion criteria to answer a particular research question or test a hypothesis (Snyder, 2019). Examining the articles and all available evidence through clear and systematic methods provides reliable findings by minimizing bias (Moher et al., 2009).

Literature review studies are divided into three; formal review (traditional, narrative review), systematic review, and meta-analysis (Petticrew & Roberts, 2006). A systematic review consists of three stages: planning, execution, reporting & generalization (Tranfield et al., 2003). This study systematically examined the literature on robotic coding in science education, following the five steps suggested by Petticrew and Roberts (2006). These steps are; Formulating the research question(s), defining inclusion/exclusion criteria, recording relevant studies systematically, evaluating the quality of selected studies, integrating major findings. In other systematic literature review studies, same procedures have also been employed (Ozsen, 2022; Uslu, 2020).

Research Questions

This study aims to conduct a literature review on the use of robotic coding in science education for the following purposes:
(a) presenting a synthesis of the empirical evidence available so far on robotic coding in science education
(b) submitting suggestions for future studies on robotic coding in science education based on the reviewed literature

Inclusion-Exclusion Criteria

A systematic search begins by defining the scope, keywords, and search terms generated from the literature and discussions within the review team (Tranfield et al., 2003). In this study, the researcher first defined the criteria before starting the systematic research protocol to select studies related to robotic coding education.

Inclusion	Exclusion
+ listed in certain indexes (Web of Knowledge and SCOPUS) + relevance to robotic coding education (in science education) + published after 2015 + written in English + a peer-reviewed article + empirical research	- country-specific indexes (e.g., Australian Education Index, British Education Index, etc.) - irrelevance to robotic coding education - published before 2015 - not in English - not a peer-reviewed article - not empirical research

Systematic Search Protocol

Studies were primarily identified through systematic searches made on relevant electronic databases. In the data collection process, WOS and Scopus databases were scanned for publications published between 2015-2022, with robotic coding education AND science education in their keywords, and 74 studies were listed. In the WOS database, 50 articles with the robotic coding education AND science education keywords in the title section were reached. In the Scopus database, 24 articles with the robotic coding education AND science education (limited to social science) keywords in the title section were found.

The search duration depended on the availability of access to electronic databases from the Eskisehir Osmangazi University library between June 2022 and August 2022.

Retrieved articles were examined in terms of title, abstract, and keywords, and studies on coding in science education were selected. The number of sources included and excluded at each review stage is documented, along with the reasons for exclusion (Tranfield et al., 2003). For example, 8 papers were not included in the study, because there were doubts about their reliability and the other 51 studies were excluded because there have not addressed coding in science education. As a result of the eliminations made according to the criteria, 15 articles suitable for this study were included (Figure 1). This study followed the PRISMA guideline, which provides an evidence-based framework and standards for conducting a systematic review. The PRISMA flowchart represents the key findings of the systematic analysis. The flowchart includes four stages: identification, screening, eligibility, and inclusion (Moher et al., 2009).

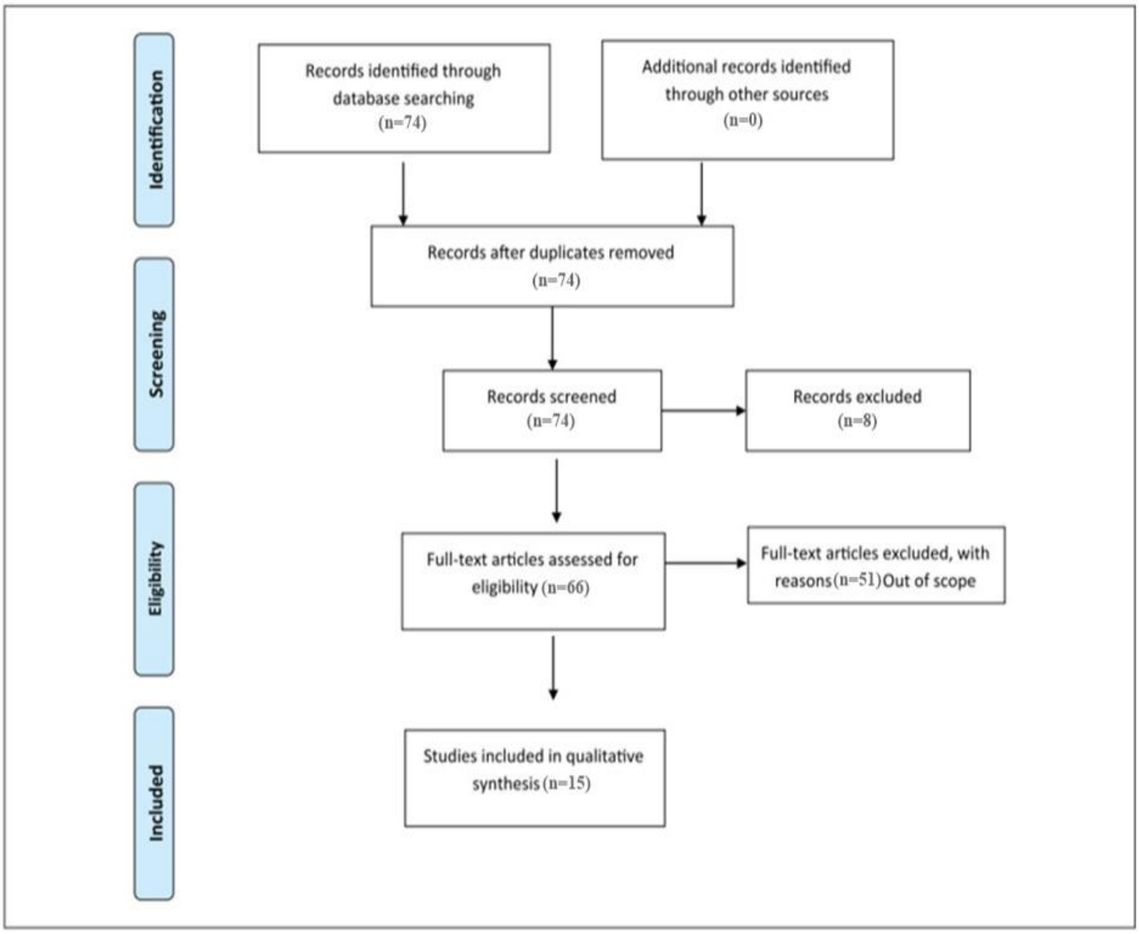

Figure 1. PRISMA Flowchart for the systematic review on "robotic coding education."

Quality Appraisal

The evaluation of the quality of qualitative research is quite controversial. There is little consensus on how to evaluate quality, who should evaluate it, and whether quality should be considered concerning "qualitative" research (Seale, 1999; Spencer et al., 2003). The quality of any systematic review or meta-synthesis depends on the quality of the works it contains. However, there is no definitive list of criteria for evaluating the quality of qualitative studies (Popay et al., 1998). The quality of qualitative research should be evaluated to avoid reaching unreliable conclusions (Thomas & Harden, 2008). All the studies selected in this review are articles published in peer-reviewed journals indexed in prestigious academic databases (WOS, SCOPUS). In addition, all selected articles consist of empirical research. Seven of these selected studies were full-text papers presented at congresses. They were excluded from the study because a consensus could not be reached on the quality of the full-text papers. Therefore, the entire methodology has been rigorously reviewed. First, a customized evaluation and data extraction form that utilizes primary research evaluation tools was developed. Individual studies in the systematic review were evaluated according to predetermined criteria and checklists to assist the process (Oxman, 1994). After the first reading of the complete text, each study underwent repeated readings and was evaluated during these readings to confirm that it met the inclusion criteria, and the findings were summarized in customized form. In most cases, dual inference processes were followed, in which two independent evaluators analyze and compare the publication and, if necessary, reconcile their findings (Tranfield et al., 2003). In this study, the data were analyzed separately by a measurement and evaluation specialist, and a consensus was reached. The findings were then examined by a field expert working on robotic coding. Thus, the credibility of the research was increased by diversifying researchers. We can say that the 15 articles selected at the end of this process exhibit a certain level of academic quality. The systematic review takes time and requires attention to detail. However, it is the most efficient and high-quality method to comprehensively identify and evaluate the literature (Mulrow, 1994).

Integration of Analysis Results

Data extraction forms are used in systematic reviews to reduce human error and bias. They usually include general information (title, author, publication details), study characteristics and specific information (details and methods), and notes on emerging themes with synthesis details (Tranfield et al., 2003).

The researcher first analyzed each selected article separately. Then, an 18-page Word document containing information about each study (author, title, keywords, year of publication, purpose of the study type, sample groups, data collection tools, data analysis techniques, results, and recommendations) was generated for effective data extraction. The researcher focused primarily on the findings/results and discussion/conclusion sections. After extracting the data, the Word documents were analyzed for similarities and differences in the results of each research report/study. Based on the similarities, three main topics were created to present the data in a way that would fit the study's purpose.

A rigorous systematic review process is used in a systematic review to collect the articles, and then a qualitative approach is adopted to evaluate them (Snyder, 2019). In this study, codes, categories, and significant themes were created by content analysis. Next, the themes obtained from the studies were synthesized, and inductive inferences were made. Then, the data analysis process and the findings were explained. A measurement-assessment expert also analyzed the codes suggested by the researcher. The analysis results were then examined by an expert working in the field of robotic coding.

Results and Discussion

The results obtained from the studies on robotic coding in science education were examined and shown in Table 1.

Table 1. Results from studies on robotic coding in science education

Theme	Category	Code	Studies
Results	Cognitive skills	21st-century skills	S4, S7, S9, S12
		Computational thinking skills	S8, S12, S13, S15
	Applications in robotic coding teaching	Integration into disciplines	S2, S4, S5, S6, S12
		Tools/hardware used in the application	S4, S5, S6
	Affective Variables	Interest	S10, S11, S14
		Motivation	S11
		Opinion	S1

Regarding robotic coding studies in science education covered in this study, they mainly focus on cognitive skills; these skills include 21st-century skills (communication, problem-solving, scientific creativity, cognitive process skills) and computational thinking skills (computational thinking, algorithmic thinking, mathematical understanding). Application studies follow them. These applications are mainly in science and engineering, and Arduino and tablet applications are used. Finally, the studies on affective variables focused on interest, motivation, and opinion. The suggestions of the studies on robotic coding in science education were examined and shown in Table 2.

Table 2. Suggestions of the studies on robotic coding in science education

Theme	Category	Code	Studies
Suggestions	Application	Integration of robotic coding (field, subject, educational environment-in-service training)	S2, S9, S11, S12
		Using robotic coding at different learning levels	S5, S7, S12
		Carrying out studies on teaching robotic coding	S4
		Carrying out studies on the use of different robotic coding programs	S15
	Future Research	Large scale studies	S1, S3, S8
		Using different data collection tools	S8, S14
		Further and in-depth research	S10
		Studies addressing gender variable	S13

The suggestions for robotic coding studies in science education are mostly related to applications and future research. The integration of robotic coding is the most mentioned suggestion for the application. These integrations cover STEM fields, different subjects, educational environments, and teacher training. This suggestion is followed by using robotic coding at different learning levels, carrying out studies on teaching robotic coding, and using different robotic coding programs.The most mentioned suggestion for future research is conducting large-scale studies, followed by using different data collection tools, carrying out further and in-depth research, and addressing the gender variable.

Conclusion

This study is considered important for revealing the trend in studies carried out in coding and robotics between 2015-2022. In addition, it is thought that it will guide future researchers who will make robotic coding in science education. Thus, the results obtained from the publications on robotic coding education in science education are discussed in this study.

Regarding the results of robotic coding studies in science education, they mainly focus on cognitive skills related to 21st-century skills (communication, problem-solving, scientific creativity, cognitive process skills) and computational thinking skills (computational thinking, algorithmic thinking, mathematical understanding). In addition, robotics technology supports the development of scientific concepts and scientific inquiry skills (Williams et al., 2007). Therefore, coding education is essential to the education of people who are equipped with 21st-century abilities, such as effective use of technology, problem-solving, and product development. Theodoropoulus et al. (2017) reported that students participating in an educational robotics competition better understood STEM concepts (Negrini & Giang, 2019). Coding contributes to individuals' acquisition of 21st-century skills. The problem-solving (Lee et al., 2011; Selby & Woollard, 2013), computational thinking, algorithmic thinking, spatial and analytical thinking skills of the students who learned to program were improved (del Castillo et al., 2019; Demirer & Sak, 2016; Monroy-Hernández & Resnick, 2008; Shin et al., 2013; Tsukamoto et al., 2017; Wing, 2006).

Then comes studies on applications in robotic coding teaching. These applications mainly involve science and engineering, and Arduino and tablet applications are used in them. According to Catlin and Robertson (2012), teaching algorithms and programming tools to students will improve their digital literacy, increase their interest and attention to school and lessons, develop problem-solving and metacognitive skills, and increase their habits of learning by doing and learning by teaching. In the last few years, many countries, seeing the value of programming, computer science, and computational thinking, have tried to change the curriculum and integrate coding into courses, which provides the required skill for computer programming (Duncan et al., 2014; Guven et al., 2022). As a result, students can integrate courses through robotics and coding education, supporting their cognitive thinking skills and learning. Jung and Won (2018) argue that studies should target how to adopt robotics in school contexts and how to adapt robotics to the current curriculum of the courses. This situation brings to mind the question of "how competent the teachers, who play an essential role in practice, are in robotic knowledge and skills." A study conducted by Wong et al. (2015) to determine the difficulties of integrating coding education into school programs revealed that teachers need training and have shortcomings regarding the curriculum. In many countries, various educational activities are organized for teachers to disseminate educational robotic activities in educational institutions (Kim et al., 2015).

The studies on affective characteristics focused on interest, motivation, and opinion. Robotics activities increase interest (Curzon, 2014; Liang et al., 2013) and motivation (Álvarez & Larrañaga, 2015; Bazylev et al., 2014;

Daher, 2022; Demirer & Sak, 2016) as they allow students to create their own products and support their learning (Lin et al., 2012; Liu et al., 2013). The results of this study support the results in the literature. However, some studies found no significant difference in students' interest, confidence, satisfaction, and motivation levels according to the use of robots in education (McGill, 2012).

Recommendations

This study aims to examine different aspects of coding and robotics education studies and share their results and suggestions with researchers. The following recommendations can be made as a result of this study. The results of robotic coding studies in science education show that they mainly focus on cognitive skills. Although these skills include some 21st-century skills, some other 21st-century skills were not addressed. Therefore, further studies addressing today's popular skills, such as innovation, critical thinking, problem-solving, cooperation, adaptation, initiative, leadership, responsibility, knowledge, media, and technology, are needed. In addition, alongside 21st-century skills, these studies included computational skills, which are related to the mathematics discipline. Therefore, there is a need for studies that include skills related to other areas of coding education as a subject under STEM education (science [scientific research, scientific reasoning], technology [scientific application and technical knowledge, effective use of resources, creativity, updated products, and systems], and engineering [thinking about design, optimizing iteration, and optimizing]). In mathematics, studies on robotic coding can address the subjects such as models and relationships, data literacy, and mathematical language. On the other hand, studies on cognitive skills mainly involved the integration of coding into science and engineering. Therefore, in science education, it is recommended to plan studies integrating robotic coding into other fields (technology, engineering, mathematics). In addition, there is a need for studies that use other tools used in coding education (Microsoft Small Basic, Alice, MIT App Inventor, and Scratch) in addition to Arduino and Tablet applications. Furthermore, studies on different affective characteristics (attitude, self-efficacy perceptions, self-efficacy beliefs, self-regulation, etc.) will be beneficial in terms of comprehensive coverage of the subject. In addition, studies can be carried out to raise code literacy awareness among students.

Regarding the results of the robotic coding studies in science education, no studies were related to the psychomotor domain. For this reason, it is recommended to include psychomotor characteristics in future studies. The suggestions for robotic coding studies in science education were mostly related to applications and future research. The integration of robotic coding was mentioned more in application suggestions. However, there are no suggestions for curriculum development. Future studies should also address curriculum development related to robotic coding.

The review of the studies in terms of their results revealed that they are mostly skill-oriented, whereas their review in terms of suggestions revealed that they mainly included applications. Teachers play a significant role in the implementation. From this point of view, in-service training on robotic coding applications should be organized for teachers.

This study is limited to 15 articles from WOS and Scopus databases, published between 2015-2022 as full-text. The current study systematically reviewed robotic coding studies in science education. In future studies, researchers should analyze robotic coding studies in different fields and periods using other types of systematic reviews like meta-synthesis or meta-analysis.

Scientific Ethics Declaration

The author declares that the scientific, ethical, and legal responsibility of this article published in the JESEH journal belongs to the author.

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