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Advantages and Challenges of STEM Education in K-12: Systematic Review and Research Synthesis

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Abstract

This study presents a systematic review of the literature on STEM education. We investigated the trends of STEM education, as well as its main advantages and challenges in K-12 settings. A total of 118 empirical studies published between 2013 and 2021 in refereed journals were included in the analysis. The findings indicate a steady increase in the number of STEM studies over the past nine years. The dominant discipline on the studies is science, while the most common level of education is upper secondary education. Most STEM interventions take place in formal settings and uses mixed research methods. The most popular educational material is simple tools, and the most measured variable is learner achievement. The most reported advantage is that STEM education helps develop of 21st century skills. On the other hand, the most reported challenge is that STEM activities are difficult to design. Further, the study discusses other advantages and challenges in detail, to map the opportunities and difficulties for students, teachers, and researchers. Finally, the study highlights some research gaps, as well as some suggestions for future research.

Introduction

STEM education is an approach where science, technology, engineering, and mathematics are presented as an integrated and multidimensional way to help understand how things work. The definition of STEM education varies significantly according to the educational level (Breiner et al., 2012). As for primary education, the integration of STEM education is not clear. Teachers at these levels focus on teaching the fundamentals of science and math, and sometimes teaching basic digital literacy. At the secondary education level, science and math are integrated into specific science fields such as physics and chemistry. The importance of STEM education at these levels lies on the fact secondary education plays a fundamental role in students' decision to study a STEM-related career in college (Freeman et al., 2014; Margot & Kettler, 2019; Roller et al., 2018). Moreover, the need for qualified STEM professionals has been stressed by different governmental and academic institutions around the world (Li et al., 2020; OECD, 2019; Olson & Riordan, 2012; Xue & Larson, 2015). These professionals are required to address contemporary demands such as global economic competitiveness, sustainable energy, sustainable agriculture, and, in general, natural resource sustainability. Consequently, these institutions have highlighted the urgency of increasing the number of students graduating from STEM careers and have joined efforts to meet the current and future demand for STEM professionals. However, despite multiple efforts to promote STEM education worldwide, the results seem to be unsatisfactory. Recent data show a declining interest in STEM careers around the world (OECD, 2021), which somehow endangers our competitiveness to face current complex challenges. According to the U.S. Bureau of Labor Statistics (BLS) the demand for STEM occupations is less than the expected increase in STEM employment in the decade 2019-2029 (Zilberman & Ice, 2021). Consequently, 3.5 million STEM jobs are projected to become vacant by 2025 in the US, a number that will increase unless effective action is taken. A similar situation has been projected by the European Centre for the Development of Vocational Training (Cedefop, 2018) and the OECD (2021). Therefore, further efforts are needed to identify effective ways to encourage students to pursue STEM-related careers.

Additionally, different studies have proven that STEM education is also beneficial for improving students' knowledge regarding subjects like those involved in STEM education, namely, science, technology, engineering, and mathematics. The study by Setiawaty et al. (2018) showed that studying these subjects in an integrated way, as proposed in STEM education, increases students learning outcomes and their motivation to learn. Similarly, the study by Wahono et al. (2020) presented evidence of significant learning gains for students learning in these subjects through the STEM approach, in contrast with those students studying the same subjects as individual subjects. Therefore, this study seeks to contribute to understanding the advantages and challenges of STEM education in K-12. Additionally, it identifies the opportunities for students, teachers, and researchers, and establishes some suggestions for future research.

Related Work

The existing literature shows that STEM offers many advantages in educational settings. For instance, STEM projects are crucial to provide not only knowledge, but also to promote positive attitudes and change students' behavior towards sustainable development (Nguyen et al., 2020; Uğraş, 2018). Also, when they participate in STEM activities, students develop essential 21st century skills such as digital literacy (Le et al., 2022; McLoughlin et al., 2020) and develop design thinking which is vital for innovation (Drymiotou et al., 2021; Li et al., 2020).

In a broader analysis, many systematic reviews have investigated the affordances of STEM education. Freeman et al. (2014) carried out a meta-analysis of 225 studies to evaluate the impact of STEM education under the frame of active learning. The authors calculated an effect size of 0.47, indicating that STEM has a medium impact on students learning. The study concluded that the success of STEM education relies on the fact that teachers favor active learning techniques over traditional lecturing. The review by Thibaut et al. (2018) analyzed 23 studies to investigate the potential of the integrated STEM education approach, as a strategy to promote motivation in STEM education. The study provides a framework for instructional practices in integrated STEM in secondary education. Their framework includes five principles: integration of STEM content, problem-centered learning, inquiry-based learning, design-based learning, and cooperative learning. Their findings show several advantages, including its applicability in the classroom and the possibility to describe integrated STEM on multiple dimensions.

Margot and Kettler (2019) reviewed 25 studies to investigate K-12 teachers' perception of STEM integration and education. Their findings indicate that while teachers value STEM education, they reported barriers such as pedagogical challenges, curriculum challenges, structural challenges, concerns about students, concerns about assessments, and lack of teacher support. Finally, Martín-Páez et al. (2019) conducted a systematic review to analyze the definition of STEM education, based on the theoretical framework proposed in 19 studies published between 2013 and 2018. Their findings indicated that the theoretical framework used in those studies focus on the measured variables rather than on STEM education. Furthermore, the study concluded that most STEM definitions provided in the studies lack a theoretical framework and, therefore, encourage the research community to achieve a consensus in this respect.

Motivation for This Systematic Review

Despite the important contributions of the aforementioned studies, there is still no clarity on the advantages and challenges associated with this educational approach. Furthermore, most studies focus on tertiary education, even though research shows that efforts should be targeted at pre-college levels (Zilberman & Ice, 2021). Therefore, a systematic review of the advantages and challenges reported in empirical studies could provide useful insights into best practices to be adopted in K-12 settings. Also, such a study would provide valuable information on the main research gaps, to guide future research leading to achieve the best of this approach to learning. This study addresses recommendations for future research in the study by Martín-Páez et al. (2019). In that sense, we analyzed the trends in STEM education regarding evolution over time, dominant discipline, educational stage, geographical location, learning environment, educational material, measured variable, and research method.

Purpose of the Study

This systematic review seeks to increase the understanding of the affordances of STEM education. This study focuses on K-12, as primary and secondary education plays a critical role in students' decision to study STEM in college, as established by previous research. Also, the Next Generation Science Standards (2013) incorporated STEM into the K-12 educational curriculum with the promise of motivating more students to pursue STEM careers.

Some literature review studies in the global field of education and technology have successfully provided the advantages and challenges of specific technologies on learning (Akçayir & Akçayir, 2017; Chauhan, 2016; Garzón et al., 2019). Following this sequence, this systematic review seeks to identify the main advantages and challenges of STEM education in K-12 settings, by answering the following research questions (RQ):

RQ1. What are the trends of STEM education in K-12?

RQ2. What are the main advantages of STEM education in K-12?

RQ3. What are the main challenges of STEM education in K-12?

To answer the research questions, the review focused on research that directly looked at K-12 student-centered STEM trends, advantages, and challenges. Therefore, to identify the trends of STEM education in K-12 (RQ1) we considered eight factors: year of publication, dominant discipline, educational stage, country, educational context, educational material, measured variable, and research method. The advantages of STEM education in K-

12 (RQ2) refer to positive outcomes reported in the studies, whereas the challenges of STEM education in K-12 (RQ3) refer to negative factors reported in the studies.

Method

This systematic review was conducted according to the PRISMA guidelines (Moher et al., 2009) and follows the recommendations of Kitchenham and Charters (2007). This procedure indicates that systematic reviews involve three main stages: Planning, conducting, and reporting the review. Below we provide thorough information on these stages.

Planning the Review

The strategy for identifying the most relevant literature to address the research questions was defined at this stage. We performed an iterative double check focused on scientific journals indexed in the Social Sciences Citation Index (SSCI) and in the Science Citation Index Expanded (SCI-E) databases. We used the following search terms: STEM education; integrated STEM; and multidisciplinary STEM; in combination with K-12; high school, secondary education, primary education, and early childhood education. The search parameters were set as follows. Document types: Article; Language: English; Category: Education Educational Research, Education Scientific Disciplines, and Multidisciplinary Sciences. Additionally, we set publication years as 2013 – 2021 since in 2013, the Next Generation Science Standards (2013) incorporated STEM into the K-12 educational curriculum. The final search was conducted on February 5, 2022 and allowed us to find 1276 studies (after removing duplicates).

Inclusion/Exclusion Criteria

The review basically examined studies specifically targeting K-12 student-centered trends, advantages, and challenges in the context of STEM education. A team of three researchers assessed each study to determine its appropriateness for inclusion and exclusion in the systematic review. This evaluation process involved multiple stages to ensure the relevance and rigor of the selected studies. First, the title and keywords of all the studies were reviewed to exclude papers that appeared to be unrelated to the research questions. Then, they read the abstract of each study. This allowed them to exclude documents such as, review papers, proceeding papers, book chapters, and papers that did not address the study's purpose. Next, they selected studies that met the following criteria:

1) empirical studies that include STEM education,
2) studies that provide sufficient information for answering the research questions, and
3) studies that include K-12 students.

Finally, they excluded papers that, despite meeting all the above criteria, did not focus on education. These criteria led to a selection of 118 empirical studies. Then, they reviewed the reference list of each paper but could not find any new studies that were relevant for the systematic review. As a result, 118 studies published from 2013 to 2021 (see Fig. 1) were found to be relevant to the purpose of this study.

Conducting the Review

The relevant data to answer the research questions was extracted from each empirical study at this stage. We designed a data extraction form to collect the following information: Study name, year of publication, dominant discipline, educational stage, country, learning environment, educational material, measured variable, research method, reported advantages, and reported challenges. Four of the researchers read each paper separately and extracted the information. As usual in systematic reviews, the Cohen's Kappa statistic was used to measure intercoder reliability. This value was found to be 0.84, which corresponds to "almost perfect agreement" as stated by Cohen (1968). Occasional disagreements were discussed and resolved by consensus with the help of all researchers.

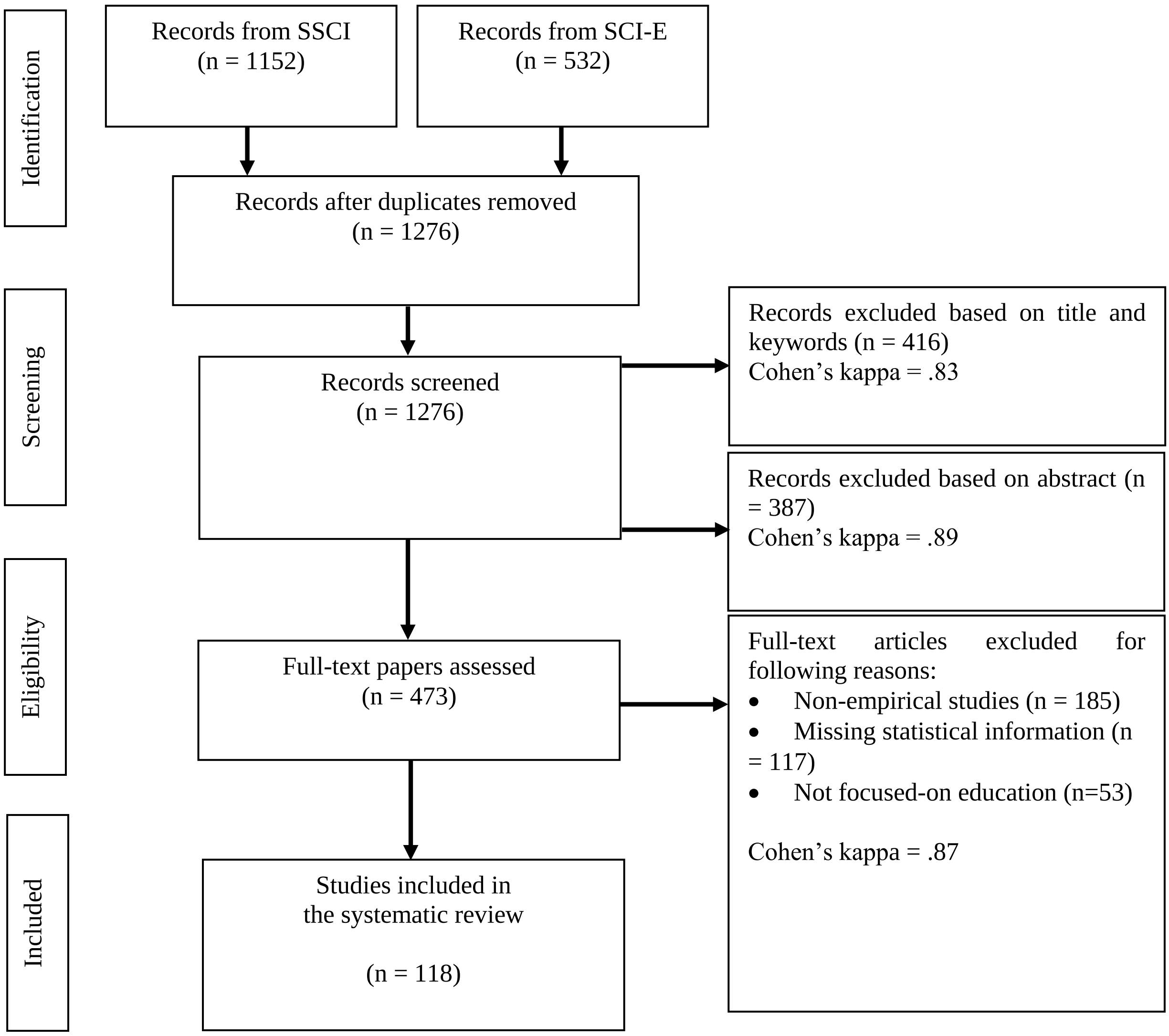

Figure 1. PRISMA Flow Diagram

Findings and Discussion

This section presents and discusses the main findings of the study according to the proposed research questions.

First, we present the trends of STEM education in K-12 settings, then we elucidate the main advantages of STEM education, and finally, we highlight its main challenges.

Trends of STEM Education in K-12 Settings

To identify the trends of STEM education in K-12 we considered eight factors: Evolution over time (year of publication), dominant discipline (subject), educational stage (level of education), country of the study (geographical location), learning environment (educational context), educational material (pedagogical resources), measured variable (variables measured in the educational experiment), and research method.

Evolution over Time

This section analyzes the distribution of the studies according to year of publication. As seen in Figure 2, it was determined that STEM studies conducted in line with the 118 studies analyzed have increased over the years. The number of studies, which was two in 2013, reached the maximum number, 29, in 2021. One of the possible explanations for this growth and is increasing popularity is that STEM approach becomes important in today's information and communication age, as it has an infrastructure that emphasizes technology and engineering, provides children with an interdisciplinary perspective and enables the realization of information concretely (Akgündüz et al., 2015). In addition, with the use of technology in the field of education (Ateş & Garzon, 2022, 2023; Sungur-Gül & Ateş, 2021) and the integration of engineering studies into education (Fayolle et al., 2021) in recent years, the demand for STEM education has increased even more (Shernof et al., 2017).

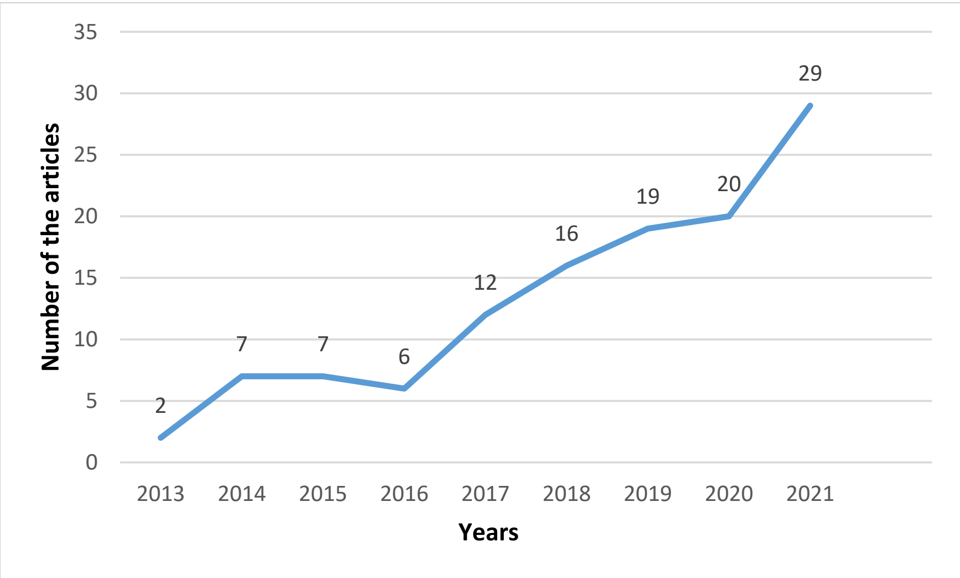

Figure 2. Number of Articles by years

Dominant Discipline

Bybee (2013) stated that studies on STEM sometimes emphasize only one discipline, sometimes four disciplines are assumed to be separate but equal, and sometimes the integration of these four disciplines is emphasized. Within this framework, the analyses revealed that there are no dominant subject areas in 16 studies, and subject areas were not specified in 44 studies. As presented in Figure 3, 21 studies (17.80%) were carried out in science, 10 studies (8.47%) were in engineering, seven (5.93%) were in technology, and two (1.69%) were in the mathematics subject area. Moreover, there are more than one dominant disciplines in 18 studies (15.25%). In general, the results showed that the most often studied discipline was science. This finding is consistent with Next Generation Science Standards (2013) reported in USA as STEM is involved in this report, which focuses heavily on science. These findings are also in line with the idea which suggests that science has a strong integrative potential and helps individuals to learn more about natural life via problem-solving experiences, inquiry, and exploration (Asghar et al., 2012).

Further, in many countries, science is taught as a whole in secondary schools, while at the high school level, science is taught as physics, chemistry and biology as sub-branches (Saudi Ministry of Education School Study Plans, 2014). While some countries, such as Arabia, use science and mathematics together in STEM education (El-Deghaidy, & Mansour, 2015), in some countries such as Türkiye, STEM education is provided by science teachers. According to Republic of Türkiye Ministry of National Education (2018), STEM is involved in science education curriculum. In the curriculum, students are expected to define a daily need or problem related to the topics covered in the units. It is desired that the problem is aimed at improving the tools, objects or systems used or encountered in daily life. Students are also asked to create strategies and use promotional tools to market the product in order to develop entrepreneurial skills. Due to the inclusion of STEM education in the science course by the Ministry of National Education in 2018, there has been a significant increase in the number of studies. Recent studies confirmed this finding. In a study conducted by Sungur-Gül et al., (2022), 87 studies in Türkiye were analyzed, it was determined that STEM studies conducted with students at the level of basic education and secondary education increased over the years. In particular, the number of studies, which was six in 2017, increased to 21 in 2018 and reached the maximum number of 34 in 2019.

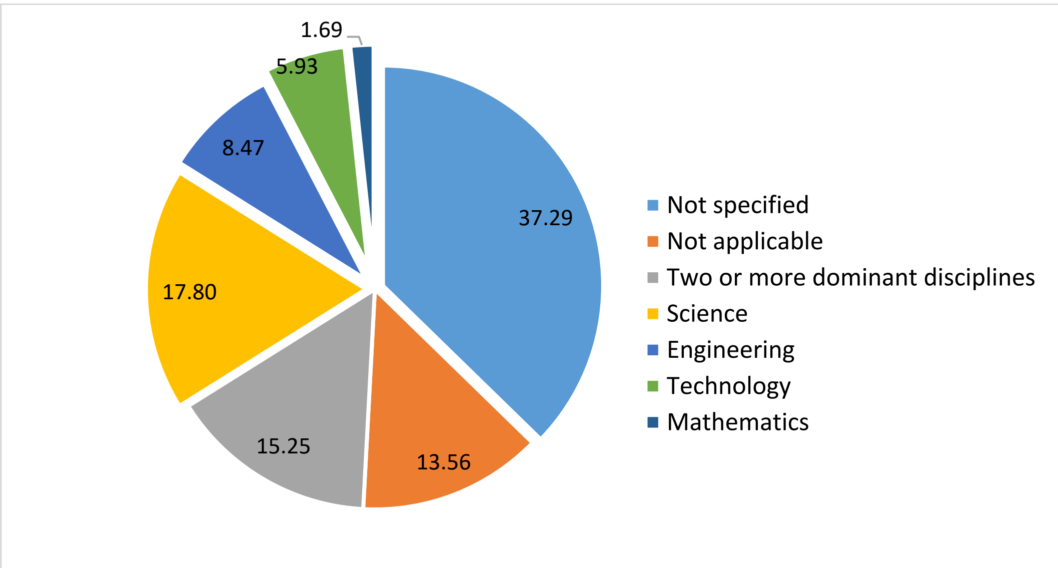

Figure 3. Distribution of the Subject Areas

Educational Stage

Among 118 studies, 51 studies were conducted with lower secondary education level, and 50 studies were conducted with upper secondary education level. Moreover, 27 studies were conducted with primary education level, and eight studies were conducted with early childhood education level. This result implied that STEM education plays an important role in existing K-12 educational system which provide science related courses and career choices rather than pre-school students. Similarly, Sungur-Gül et al., (2022) reviewed 87 studies found that most of the studies were conducted with secondary school students. Of the studies analyzed, 61 were conducted with secondary school students, 10 with high school students, eight with primary school students, and six with pre-school students. Earlier STEM education based studies also reported that with the introduction of science and mathematics education at the primary and secondary school level, students interest in these courses. Thus, students who find science and mathematics useful and are interested in science-mathematics related careers are more likely to pursue STEM fields (Maltese & Tai, 2011; Museus et al., 2011).

Geographical Location

As shown in Figure 4, almost half of the studies were conducted in North America, 35 studies were conducted in Asia, 12 in Europe, four in Oceania, and one study was conducted in Africa.

North America (58)	USA (56)	Canada (2)	
Asia (35)	China (11) Taiwan (10)	Malaysia (6) Turkey (5)	Israel (2) Palestine (1)
Europe (12)	Spain (3) Netherlands (2) Belgium (2)	Denmark (1) England (1) Estonia (1)	Germany (1) Norway (1) Switzerland (1)
Oceania (4)	Australia (4)		
Africa (1)	Nigeria (1)		

Figure 4. Distribution of the Countries

Geographical location was not specified in eight studies. It is remarkable that no study conducted in South America was detected. More specifically, 49.15% of the studies were conducted in North America, and 47.46% of all the 118 studies were conducted in the USA. It may be due to the large role that the USA has played in the historical development of STEM. In the birth and development of the STEM, the USA made significant contributions to the process of pursuing a career of individuals (Bybee, 2013). Earlier studies in their systematic literature reviews stated the USA as the country where studies on STEM education were conducted more than other countries (e.g., Margot & Kettler, 2019). However, since the journals examined in this study were published in English language, there may be articles that were published in other languages.

Learning Environment

While the learning environment of 65 studies was formal setting, 20 studies were carried out in informal settings. 13 studies were conducted in multiple setting (both formal and informal settings). No learning environment was specified in 20 studies. The most important reason why most of the practices are designed in-school environment could be due to the limited time per lesson (Stoeger et al., 2013), difficult to obtain parental approval, and teachers' reluctance to engage in activities in out-of-school environments (Toma & Greca, 2018). In a study Chen and Lin (2019), it was emphasized that researchers prefer to study in-school environment since classroom environment is needed to conduct certain STEM trainings.

Educational Material

Among educational materials, simple tools in STEM education are used more frequently (*N*=58). The most important reason for this may be due to economy, time and travel (Siew et. al., 2016). On the other hand, robotic materials and coding programs were used in most of the studies (*N*=25) since robotic materials and coding programs supports students' collaboration and problem-solving, creative thinking, and higher-order thinking skills and promote their STEM learning such as measurement and spatial concepts (Blackley, & Howell, 2019; Romero & Dupont, 2016; Savard & Highfield 2015). In line with earlier studies (e.g., Cheng & Tsai, 2013), virtual reality and augmented reality were less preferred due to the high price (Küçük et al., 2016), teacher resistance and technical problems (Sırakaya & Sırakaya, 2022), difficulty of developing educational materials for Virtual Reality and Augmented Reality (Chang et al., 2016) and time-consuming (Laine et al., 2016). Further, any educational material was not involved in 12 studies, and no material was specified in 19 studies (see Figure 5).

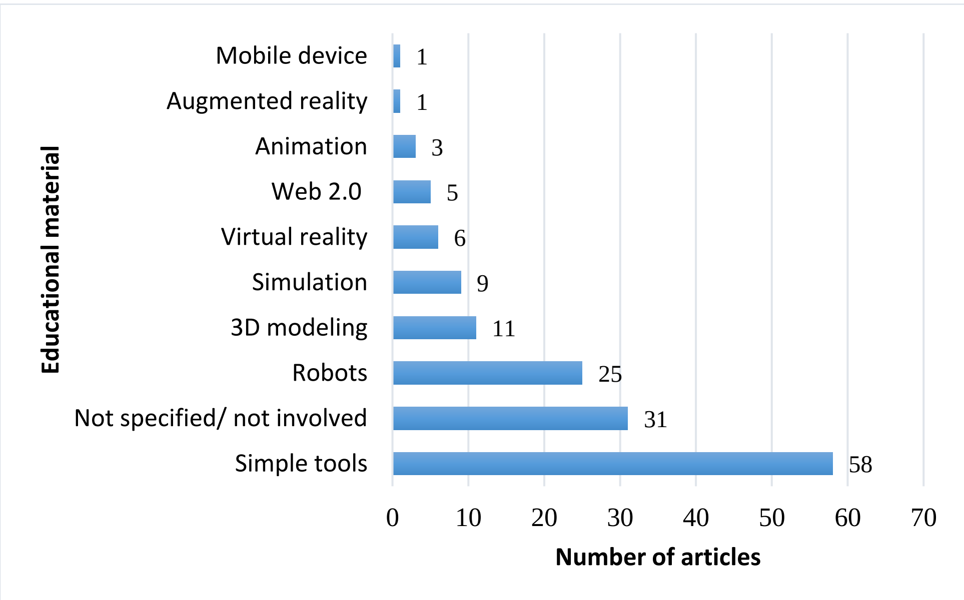

Figure 5. Distribution of the Educational Materials

Measured Variable

The examined variables are explored as categories. Since one study can include more than one variable, the total frequency is high. For each sub-category, sample research is given. The major variables examined in the articles are: "Learner achievement", "learner skills", "learner career development", "STEM dispositions", "learning experience" and "other". According to the results, 52 studies (44.1%) focused on the students' achievement regarding the STEM disciplines (science, technology, engineering, and mathematics), while only seven studies (5.9%) investigated their achievement on non-STEM disciplines including reading, social studies, language, and history. The second category, learner skills, includes five sub-categories: 21st century, STEM, higher order thinking, engineering-design, and science process skills. As seen in Table 1, 21st century skills are the most examined variable (34.7%) in the studies. In learner career development category, it was found that researchers mostly (20.3%) investigated the students' interest in STEM careers. In STEM dispositions category, STEM interest is the most commonly (14.4%) investigated variable due to the easy measurement, while beliefs in technology (0.8%) and perception of the learning environment (0.8%) are the least ones. Moreover, two articles (1.7%) were determined directly under the STEM dispositions category. The analyses revealed that 10 studies (8.5%) investigated individuals' STEM learning experience. Also, some other variables such as rate of attendance (5.1%), awareness of the equity and social justice issues (1.7%), readiness (0.8%), parent endorsement of the school (0.8%), usefulness in practice (0.8%), and memorable experience (0.8%) were all examined in the reviewed articles.

These study reports carried out provide clues that STEM education will play an important role in determining the future world and the vocational preferences of individuals (Emembolu et. al., 2020; Stringer et. al., 2020). For example, the fact that 21st century skills are among the most researched subjects seems to be in line with the targets set by these skills in education (Valtonen et al., 2021). Education is the very powerful factor to provide longer-term change in the formation of school achievements and career choices (Weis et al., 2015; Mohr-Schroeder et. al., 2020; Stringer et. al., 2020) and integration of 21st-century skills (Hakkinen et al. 2017).

Table 1. Frequency of the Examined Variables in the Articles

Categories	Sub-categories	F	%	Sample article
Learner achievement	STEM disciplines	52	44.1	Eisenhart et al. (2015)
	Non-STEM disciplines	7	5.9	Gnagey & Lavertu (2016)
Learner skills	21st century skills	41	34.7	Stehle & Peters-Burton (2020)
	STEM skills	9	7.6	Aldemir & Kermani (2017)
	Engineering design skills	4	3.4	Chiang et. al. (2020)
	Higher-order thinking skills	2	1.7	Fan & Yu (2017)
	Science process skills	2	1.7	Özkul & Özden (2020)
Learner	Interest in STEM careers	24	20.3	Maiorca et. al. (2020)
	Motivation towards STEM careers	10	8.5	Kotkas et al. (2017)
	STEM career intention	9	7.6	Bottia et al. (2018)
	STEM career awareness/identity	8	6.8	Stringer et. al. (2020)

Categories	Sub-categories	F	%	Sample article
career development	Attitude towards STEM careers	7	5.9	Dickerson et al (2014)
	STEM career knowledge	4	3.4	Emembolu et. al. (2020)
	Perception of STEM careers	3	2.5	Chen et. al. (2020)
	STEM career self-efficacy	2	1.7	Maiorca et. al. (2020)
Learner STEM dispositions	STEM interest	17	14.4	Shahali et al. (2017)
	Attitude towards STEM	15	12.7	Prieto & Dugar (2017)
	Motivation towards STEM	12	10.2	Vennix et al. (2018)
	Emotional satisfaction	14	11.9	Lamb et al. (2015)
	Self-efficacy beliefs in STEM	8	6.8	Means et al. (2016)
	Motivation	4	3.4	Tsz-Kit et al. (2021)
	Awareness of STEM disciplines	2	1.7	Chung et al. (2021)
	Beliefs in science	2	1.7	Stevens et al. (2016)
	Beliefs in technology	1	0.8	Lin et al. (2021)
	Perception of the learning environment	1	0.8	Vennix et al. (2018)
Learning experience	STEM learning experience	10	8.5	Tippett & Milford (2017)
	Active learning experience	9	7.6	Barak & Assal (2018)
	Authentic learning experience	8	6.8	Dasgupta et al. (2019)
	Inquiry based learning experience	2	1.7	Sahin et al. (2014)
	Flow experience	1	0.8	Guan et al. (2021)
	Technology acceptance	1	0.8	Mater at. al. (2020)
Other	Rate of attendance	6	5.1	Stevens et al., 2016
	Awareness of the equity and social justice issues	2	1.7	Mildenhall et al. (2019)
	Readiness	1	0.8	Johnson & Sondergeld (2020)
	Parent endorsement of the school	1	0.8	Miller & Roehrig (2018)
	Usefulness in practice	1	0.8	Özcan & Koca (2019)
	Memorable experience	1	0.8	Lynch et al. (2018)

Research Method

According to results of the analysis, 52 articles (44.07%) were quantitative, 41 (34.75%) were mixed, 23 (19.49%) were qualitative, and two articles (1.69%) were conducted using the design-based research method (see Fig. 6). Quantitative and mixed studies focused on ideas of individuals about STEM education in psychological, volitional and non-volitional contexts (e.g., Duran et al., 2014; Laut et al, 2015; Leonard et al, 2016) and improve students' STEM-related content knowledge and attitudes, as well as its suitability for the after school environment (e.g., Moreno et al, 2016), while qualitative studies aimed to promote interest, career awareness, self-efficacy, and knowledge in STEM fields (e.g., Friedman et al. 2017; Gilliam et al., 2017).

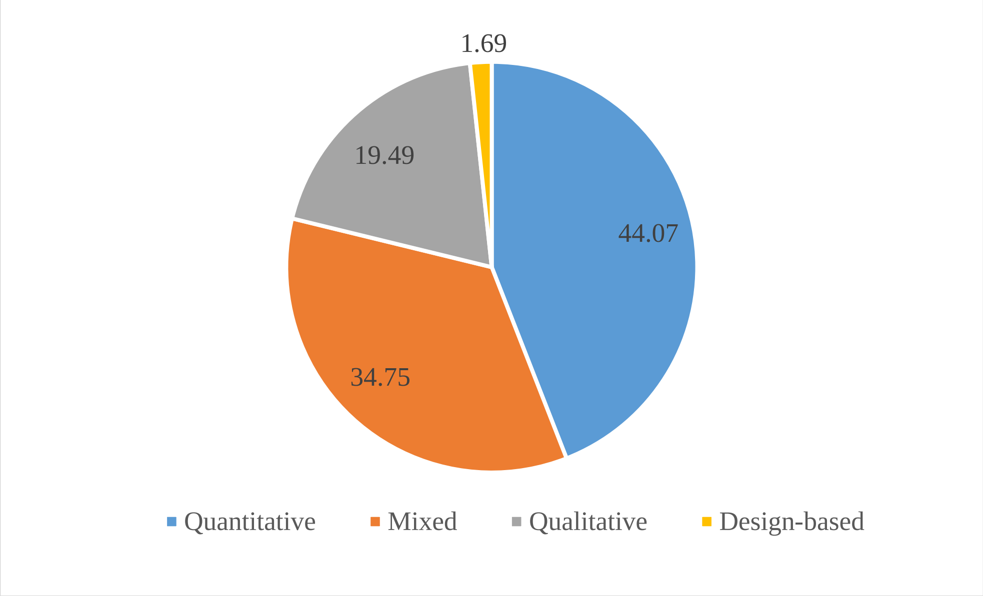

Figure. 6. Distribution of the Research Methods

Advantages of STEM Education in K-12

In this section, the sub-categories are generated in accordance with the advantages of STEM education reported in the studies. The advantages of STEM education are arranged into six categories (learner achievement, learner skills, learner career development, learner STEM dispositions, learning experience, and other categories). Restricting the studies to K-12 students induced to the emergence of the advantages of STEM education mostly for students. Because some studies involved more than one advantage, it is possible for percentages of the sub-categories to be more than 100%. Detailed information regarding the sub-categories of the categories is given within the six headings and presented in Table 2.

Learner Achievement

The advantages of STEM education which are related to learners' achievement (academic knowledge or conceptual understandings) are combined under this category. In this category, two sub-categories are generated as “increase achievement in STEM disciplines” and “increase achievement in non-STEM disciplines”. According to the findings, STEM education can increase students’ achievement in STEM and non-STEM disciplines (Weis et al., 2015; Gnagey & Lavertu, 2016). It is important to note that some studies reported increasing students’ achievement in all four STEM disciplines (16%), otherwise the majority of the studies (31%) reported increasing students’ achievement in only some disciplines in STEM, such as increase students’ achievement in science. In sum, nearly half of the studies (44%) emphasized increasing the students’ achievement in STEM disciplines. For example, in a study conducted by Erdogan et al. (2016), they investigated how well STEM project-based learning influences students' science achievement through the implementation. The results showed that students who had STEM Project-Based Learning had higher level of achievement than students who hadn’t get STEM based implementations. In another study, Wiswall et al. (2014) found that attending a STEM high school improved students’ science and mathematics performances. According to most of results, it can be concluded that STEM education may improve students' learning performance which play an important role in quality education (Akçayır & Akçayır, 2018), and studies mostly focused on academic achievement in STEM disciplines. Moreover, non-STEM disciplines including reading, social studies, language, and history were less investigated (6%) even though they are important in educational settings.

Learner Skills

According to the studies, the most remarkable sub-category is developing 21st century skills (35%) in the category named "learner skills". Information, media and technology, computational thinking, creativity and innovation, spatial, mental rotation, self-regulation, mechanical reasoning, communication, and collaboration skills determined in the articles were coded as 21st century skills. Studies focused on either directly developing a few of these skills or 21st century skills of students. In addition, improving STEM skills (8%), focusing on engineering design skills (3%), developing higher orders skills (2%), and improving science process skills (2%) are less reported skills from the viewpoint of the advantage of STEM education on learner skills. These studies showed that 21st century skills are the most investigated learner skill in STEM education studies. These results are in line with the purpose of the emergence of the STEM education and the idea which proposed that integration STEM education to twenty first century skills' may strengthen learners' digital literacy, and critical thinking, and creativity (Lou et al., 2017; Nieveen & Plomp, 2018). Considering the studies under this topic, although there are not as many findings as 21 century skills, studies in recent years show that STEM education also improves students' STEM skills (e.g., Moreno et. al., 2016), engineering design skills (e.g. Ata-Aktürk & Demircan, 2020), develops higher-order thinking skills (e.g., Fan & Yu, 2017) and improves science process skills (e.g., Özkul & Özden, 2020). STEM based skills, which are frequently examined in studies, also affect the policies of governments. For example, Banerjee (2017) stated that since STEM skills play an important role for economic growth, governments funded some STEM enrichment and enhancement activities for economic development. In another study Ata-Aktürk and Demircan (2020) developed a STEM-based parent involved engineering design curriculum and found that STEM education improved students' thinking and engineering skills which are in line with the results of Dorie and Cardella (2014), Gunning et al. (2016), Moomaw and Davis (2010), Smetana et al. (2012), and Stone-MacDonald et al. (2015).

Learner Career Development

The advantages of STEM education related to students' career development are grouped under the learner career development category. While some studies reported the development of careers for all STEM disciplines, a few of the studies provided career development about some of the four STEM disciplines (e.g. science, and technology career). In conclusion, studies that provide career development for at least one of the STEM disciplines are evaluated as sub-categories about STEM career development. In the articles, almost 20% of examined studies presented that STEM education increases students' interest in STEM careers (e.g. Evans et. al., 2014; Friedman et. al., 2017; Jensen & Sjaastad, 2013; Kurban & Cabrera, 2020). Moreover, a few of researchers determined advantages such as increasing students' motivation towards STEM careers (9%), providing STEM career intention (8%), increasing STEM career awareness (7%), developing positive attitude towards STEM careers (6%), promoting STEM career knowledge (3%), improving positive perceptions of STEM careers (3%), and developing STEM career self-efficacy (2%). These results are in line with K-12 educational goals, which is to prepare students for careers in STEM in the United States (Sadler et al., 2012).

Attachment to STEM Education

The advantages of STEM education in terms of attachment to STEM education (such as interest, attitude, perception, motivation) are examined under this category. According to the findings, STEM education increases students' STEM interest (14%), develops positive attitudes towards STEM (13%), and increases motivation towards STEM (10%). Moreover a few of the studies indicated that STEM education provides emotional satisfaction (8%), increases self-efficacy beliefs in STEM disciplines (7%), provides feeling more confident (4%), increases motivation (3%), strengthens awareness of STEM disciplines (2%), develops positive beliefs in science (2%), develops positive beliefs in technology (1%), and improve positive perceptions of learning environment (1%). Moreover, the findings of two articles (2%) were determined directly as STEM dispositions. For example, Leonard et al. (2016) found that using LEGO (A(R)) EV3 robotics and games using scalable game design software increased students' self-efficacy and STEM attitudes. In Chittum's (2017) study, afterschool STEM program fostered students' motivation and engagement toward STEM education. Stevens et al. (2016) developed a program called iSTEM which combine two approaches including in-school mentoring with out-of-school informal science education experiences and examined effect of this program. The results showed that iSTEM program fostered students' engagement and interest in STEM learning, and science beliefs.

Learning Experience

The study's findings showed that STEM education has advantages in regard of learning experience. Studies reported that STEM education provides STEM learning experience (9%), active learning experience (8%), and authentic learning experience (7%). These results are consistent with earlier study reports which stated that since STEM is seen as too uninteresting, boring, and challenging (PCAST, 2010), students tend to study courses which are not related to STEM. However, students who are more likely to interest in STEM-related areas (After-School Alliance, 2015) may have more learning experience in STEM (English, 2019; King & Pringle, 2018; Roberts et. al., 2018). In this regard, involving in STEM experience can increase students' interest in STEM (Baran et al. 2016; Kitchen et al. 2018; Mohr-Schroeder et al. 2014). There are some more other learning experiences, such as promoting inquiry-based learning experience (2%), being effective in improving technology acceptance (1%), and developing flow experience (1%) were less reported in the studies. According to Mater et. al. (2020), technology-rich school environments such as robotics for STEM education can make the learning process more fun and exciting for the students and develop technology acceptance.

Other

In some other studies, it was reported that STEM education can be used to increase awareness of the equity and social justice issues, decrease the odds of school dropout, and increase parent endorsement of the school. These sub-categories were grouped under the "other" category. Since STEM education enables students to gain practical experience, STEM education also provides usefulness in practice (1%) and promotes memorable experience (1%) according to the researchers (Chen & Lin, 2019; Dickerson et. al., 2014; Plasman & Gottfried, 2018; Saw, 2019).

Table 2. The Advantages of STEM Education

Categories	Sub-categories	f	%	Sample research
Learner achievement	increases achievement in STEM disciplines	52	44.1	Duran et. al. (2014)
	increases achievement in non-STEM disciplines	7	5.9	Gnagey & Lavertu (2016)
Learner skills	develops 21st century skills	41	34.7	Fan & Yu (2017)
	improves STEM skills	9	7.6	Moreno et. al. (2016)
	focus on engineering design skills	4	3.4	Ata-Aktürk & Demircan (2020)
	develops higher-order thinking skills	2	1.7	Fan & Yu (2017)
	improves science process skills	2	1.7	Özkul & Özden (2020)
Learner career development	increases interest in STEM careers	24	20.3	Jensen & Sjaastad (2013)
	increases motivation towards STEM careers	10	8.5	Evans et. al. (2014)
	provides STEM career intention	9	7.6	Kurban & Cabrera (2020)
	increases STEM career awareness (identity)	8	6.8	Friedman et. al. (2017)
	improve positive attitude towards STEM careers	7	5.9	Vennix et. al. (2018)
	promotes STEM career knowledge	4	3.4	Bottia et. al. (2018)
	improves positive perceptions of STEM careers	3	2.5	Chen et. al. (2020)
	develops STEM career self-efficacy	2	1.7	Maiorca et. al. (2020)
Attachment to STEM education	increases STEM interest	17	14.4	King & Pringle (2018)
	improve positive attitudes towards STEM	15	12.7	Toma & Greca (2018)
	increases motivation towards STEM	12	10.2	Evans et. al. (2014)
	provides emotional satisfaction	9	7.6	Mohd Shahali et al. (2019)
	increases self-efficacy beliefs in STEM disciplines	8	6.8	Barak & Assal (2018)
	ensures feeling more confident	5	4.2	Chen & Lin (2019)
	increases motivation	4	3.4	Miller & Roehrig (2018)
	strengthens awareness of STEM disciplines	2	1.7	Laut et. al. (2015)
	develops positive beliefs in science	2	1.7	Stevens et. al. (2016)
	develops positive beliefs in	1	0.8	Vallera & Bodzin (2020)

	technology			
	increases positive perceptions of the learning environment	1	0.8	Vennix et. al. (2018)
Learning experience	provides STEM learning experience	10	8.5	English (2019)
	provides active learning experience	9	7.6	King & Pringle (2018)
	provides authentic learning experience	8	6.8	Roberts et. al. (2018)
	promotes inquiry-based learning experience	2	1.7	Sahin et. al. (2014)
	improves technology acceptance	1	0.8	Mater et. al. (2020)
	develops flow experience	1	0.8	Wang & Chiang (2020)
Other	increases awareness of the equity and social justice issues	2	1.7	Saw (2019)
	decreases the odds of school dropout	2	1.7	Plasman & Gottfried (2018)
	increases parent endorsement of the school	1	0.8	Chen & Lin (2019)
	provides usefulness in practice	1	0.8	Dickerson et. al (2014)
	promotes memorable experience	1	0.8	Dickerson et. al (2014)

Challenges of STEM Education in K-12

Even though STEM education provides many advantages in educational settings, a few challenges were highlighted in the studies (see Table 3).

Table 3. The Challenges of STEM Education

Challenges	f	%	Sample research
highly technical	3	2.54	Friedman et al. (2017)
requires more time	2	1.69	Stoeger et al. (2013)
difficult to design STEM activities	2	1.69	English (2019)
highly specific area of study	1	0.85	Friedman et al. (2017)
reduce interest in engineering	1	0.85	Wang & Chiang (2020)
reduce interest in technology	1	0.85	Wang & Chiang (2020)
causes focusing on product rather than problem	1	0.85	English (2019)
equip students with limited scientific concepts	1	0.85	Siew et. al. (2016)
require a suitable classroom environment	1	0.85	Chen & Lin (2019)
Activities require creativity skill	1	0.85	Siew & Ambo (2018)
reluctant teachers to implement STEM	1	0.85	Toma & Greca (2018)

Because STEM education incorporates of designing an interdisciplinary product (Thibaut et al., 2018), studies indicated that STEM education is highly technical (3%), requires more time (2%), and it is difficult to design STEM activities (2%), and being a specific area of study (1%). Researchers stated that the time problem constitutes an important problem in the development of STEM practices and work in groups (e.g., Sümen & Çalışıcı, 2016). Further, for example, Friedman et al. (2017) stated that STEM practices are highly technical and necessitate highly specific area of study. In addition to these, studies indicated that STEM education reduces interest in engineering (1%), and reduce interest in technology (1%). Researchers also reported challenges as requiring a suitable classroom environment for group work (1%), requiring creativity skill (1%) to solve a problem or design a product, focusing on product rather than the problem (1%), and equipping students with limited scientific concepts. Chen and Lin (2019) stated that researchers have difficulty in designing STEM implementations since they require a suitable classroom environment. From another perspective, STEM education is relatively new approach compared to conventionally structured course for teachers, this situation can cause being reluctant teachers to implement STEM education (1%).

Identified Gaps and Future Studies

There are several gaps identified in this systematic review. Firstly, we found only 92 studies published in peer-reviewed journals on the topic of STEM. More study should take place in this field. Secondly, the majority of the studies were conducted in middle schools and of the 92 studies only five studies were involved in preschool study settings. Therefore, relevant literature has an important need in preschool level. Thirdly, an important number of studies focused on the science research area. In order to understand STEM education from an interdisciplinary perspective, studies should also focus on the fields of mathematics, engineering and technology. Fourthly, most of the studies were implemented using quantitative research methods. To gain an in-depth perspective, future studies should focus more on qualitative and mixed method research. Fifthly, it was revealed that studies were carried out more frequently in certain countries such as the USA. Finally, although many studies examined advantages of STEM education, while only a few studies investigated challenges of STEM education. More studies should be paid to challenges of STEM to better understand the difficulties that researchers are likely to experience.

Limitations

This study aims to systematically review STEM studies published in the English language and indexed in SCI/SSCI databases. While this approach ensures a comprehensive analysis of the available literature, it also introduces certain limitations. Firstly, findings related to the results obtained from studies indexed in different databases or published in languages other than English are not represented within the scope of the present study. This limitation potentially excludes relevant research from non-English speaking countries or those not indexed in the specified databases. Secondly, the study's focus is primarily on K-12 students, which may limit the generalizability of the findings to other educational levels. Consequently, interpretations beyond this specific sample should be made with caution, as they may not accurately reflect the broader context of STEM education. Furthermore, the review does not include research related to teacher preparation or curricular design in STEM education. These areas were not encompassed in the study's objectives, as the focus was on direct K-12 student-centered STEM trends, advantages, and challenges. While the exclusion of these topics narrows the scope, it allows for a more in-depth examination of the student-centered aspects of STEM education. Lastly, we have revised our research questions to be more specific and better aligned with the study's purpose, which should enhance the clarity and coherence of our systematic review.

Conclusions

The current review contributed the STEM education literature in K-12 education settings regarding year of publication, dominant discipline, educational stage, geographical location, educational context, educational material, measured variable, and research method. In addition, this study reviewed studies with regards to advantages and disadvantages of STEM education. In this study, a total of 92 studies were examined between 2013 and 2021. The results of the study showed that interest in STEM and the number of researches carried out has increased every year. The most examined subject matter was science and the major study design is quantitative research. The study also showed that most of the studies were conducted with middle school students, used simple tools, preferred in-school environment, and involved in the USA. As examined variable, the most preferred variable in the articles is 'Learner Achievement'. Considering advantages and challenges regarding STEM education, it was found that among the most important advantages of STEM education, earlier studies stated that STEM increases achievement, develops 21_{st} century skills, increases interest in STEM careers, increases STEM interest, improves positive attitudes, and increases motivation. There are several studies which listed mostly disadvantages of STEM applications as time problem, and challenges related to designing STEM activities.

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