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Mathematical Critical Thinking Skills through STEM/STEAM Approach: A Systematic Literature Review

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Abstract: The STEM/STEAM approach provides opportunities for students to develop critical thinking skills through the integration of different disciplines. This study aims to provide a comprehensive picture of the extent to which the STEM/STEAM approach develops critical thinking skills in mathematics teaching and learning. A systematic literature review (SLR) was conducted using guidelines from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). We searched Springer Link, Eric, and Google Scholar for 21 articles on critical thinking published between 2018 and 2022. The results show that most of the lead authors studying critical thinking through STEM/STEAM are from Indonesia, with fewer contributions coming from the United States, Taiwan, Saudi Arabia, Turkey, Japan, and Malaysia. The most common research methods used are quantitative research and R & D. These methods correspond to the types of data collection tools used by researchers and critical thinking tests to identify critical thinking skills for the cognitive aspect and questionnaires for the affective aspect. The best practice for improving learner's mathematical critical thinking skills in STEM/STEAM is Project-Based Learning (PBL). However, this practice is not used by many development researchers. The authors find distinctive features in the interventions used by researchers to improve the critical thinking of learners from each country. The most common intervention was an analysis of the implementation of the STEM/STEAM approach in Indonesia. Many Indonesian researchers also developed learning models and media. Other countries focused more on computer-based activities, developing community programs, and identifying participants' perceptions of critical thinking. These differences give each country its own characteristics in improving and identifying the critical thinking skills of its people. These differences in practices and interventions can also provide alternatives for researchers in their research on critical thinking through the STEM/STEAM approach.

Keywords: Critical thinking, STEM, STEAM, Mathematic literature review

Introduction

In facing the world's challenges in the future, critical thinking is a very important ability to sort out correct information from wrong or biased information. Critical thinking focuses on deciding what to do or believe (Ennis, 1987). The amount of information that is abundant, spread without accurate validation, and cannot be trusted, requires students to be able to filter information, analyze its sources, and make decisions based on valid evidence. The demands of the modern world, where everyone has to find, select and use information in their lives, is one of the reasons why the development of critical thinking skills is essential. (Maulana, 2017). The development of critical thinking skills is often listed as the most important reason for formal education because the ability to think critically is essential for success in the contemporary world where the rate at which new

knowledge is created is rapidly accelerating (Marin & Halpern, 2011). Schools are required to provide education that is able to foster student character to think critically, creatively, be able to communicate, and collaborate sebagai keterampilan yang dibutuhkan abad 21 (Setiana et al., 2021). Critical thinking became an important skill that helps students improve their ability to make judgments, inform well, explain reasons, and solve unknown problems (Facione, 1991).

Although everyone agrees that critical thinking is very important, critical thinking does not come naturally to anyone, regardless of background. 'critical thinking is hard . . . and most people are just not very good at it' (Gelder, 2005). The difficulty of having critical thinking skills can be seen in the low achievement of critical thinking skills in the field of mathematics education. In Indonesia, students' ability to think critically about mathematics is still relatively low (Farib et al., 2019). This fact is supported by the results of research between 2017 and 2023 at the elementary, junior high and senior high school levels which state that the average mathematical critical thinking ability of students is low. (Anggraini et al., 2022; Benyamin et al., 2021; Danaryanti & Lestari, 2018; Dores et al., 2020; Irawan et al., 2017; Septiana et al., 2019; Widana & Widyastiti, 2023). In other countries such as Malaysia, the scores of high school graduates obtained in the National Examination do not reflect mathematical thinking skills including critical thinking (Singh et al., 2018). Then, a study in Turkey revealed that out of 63 articles published in ERIC in 2016-2019, only 43% of articles focused on teaching approaches to critical thinking. (Costa et al., 2020).

The low level of critical thinking skills is influenced by several things, including students' tendency to memorise formulas rather than concepts design (Andriani & Jatmiko, 2018). Helf and Scharff (2017) believed that the deficiency in critical thinking education was due to the faculty not having the knowledge needed to teach these skills effectively. Teachers should be able to find and choose learning strategies that are appropriate to the characteristics of the learners (Susmariani et al., 2022), because critical thinking skills in mathematics can be developed by using the right learning model. (Widana & Widyastiti, 2023).

Many studies have been conducted to develop critical thinking skills. Many education programs provide learners with activities and experiences to foster and develop their critical thinking skills (Evangelisto, 2021). However, the results obtained are still not at their best. Multiple studies have concluded that higher education at large has not been very effective in developing students' critical thinking skills (e.g. Arum & Roksa, 2011). This lack of development of critical thinking skills is not due to a lack of motivation or indifference from teachers, but rather to a misunderstanding and lack of awareness of effective techniques for teaching these critical thinking skills to students (Heft & Scharff, 2017).

Based on these conditions, it is important to examine how these critical thinking skills can be developed effectively, especially in the field of mathematics. Holmes et al said that critical thinking skills can be taught (2015), and a mixture of explicit and content centered instruction is best (Ennis, 2018). Suggested teaching techniques included skill based rather than fact-based instruction and assessment (Ernst & Glennie, 2015; Nelson, 2017). Specific techniques suggested in the literature included similar techniques as STEM teachers, modellig the desired outcome, allowing students to practice and assessing based on skill learned (Co, 2019, Hacisalihaglu et al., 2018; Nelson et al, 2018). Studying in a transdisciplinary STEAM space can help students develop creativity collaboratively, and the essence of this position is STEAM as a collaborative practice (Henriksen et al., 2019; Liao et al., 2016). In this learning activity, students can build confidence to make selective choices for their lives and be able to face future challenges. The position of STEM/STEAM in this context is that of a learning approach.

The STEM/STEAM approach integrates disciplines such as science, technology, engineering, art, and mathematics that require students to understand the relationships between different concepts and apply knowledge to solve problems. Students are invited to think deeply, analyze information and evaluate ideas by integrating disciplines. This process requires critical thinking skills in understanding the context of the problem as a whole, analyzing, evaluating and determining the correct solution. Well-integrated instruction provides opportunities for students to learn in more relevant and stimulating experiences, encouraging the use of higher-level critical thinking skills (Stohlmann et al., 2012). Therefore, the STEM/STEAM approach could enhance students' critical thinking skills.

The STEM/STEAM approach in improving students' critical thinking skills is certainly an important demand in the world of education. Although the teaching of critical thinking has been extensively studied in other disciplines, there is a surprising the lack of critical thinking research in STEM (Evangelisto, 2021). This study will examine the extent of research that has been done previously on the relationship between the STEM/STEAM approach and students' critical thinking skills. This research is conducted to see how the

application of the STEM/STEAM approach to improve students' mathematical critical thinking skills is generally carried out in various parts of the world. It will also reveal the types of research designs and best practices that have been conducted to improve mathematical critical thinking through the STEM/STEAM approach. We will also analyze the types of interventions that researchers have undertaken to illustrate the distinctive nature of their research.

To achieve the objectives of this study, the Systematic Literature Review (SLR) method will be used to help researchers collect, review and synthesize relevant studies that have been conducted previously. This method can contribute to further research that examines the improvement of mathematical critical thinking skills through STEM /STEAM approach and contributes to educational attainment worldwide that has yet to make STEAM a critical, integrated.

Literature Review

Critical Thinking Skills

John Dewey (1910) described the concept of critical thinking more broadly by referring to it as reflective thinking. Reflective thinking involves actively, persistently, and carefully considering any belief or supposed form of knowledge in light of the supporting grounds and the potential further conclusions it may lead to (Dewey, 1910). The process of thoughtful and confident consideration is a critical attitude that is exercised when receiving or acquiring information from others. It avoids passivity and mere acceptance of acquired information without justifying its validity.

Critical thinking skills can be developed through the process of learning mathematics. Improving critical thinking skills in mathematics learning is crucial for students to develop problem-solving abilities and analytical thinking. Mathematics teachers play a significant role in fostering critical thinking skills among their students (As'ari et al., 2017). Teachers can employ various teaching approaches with stages that sharpen students' thinking abilities through various project-based learning. The process of critical thinking in learning mathematics can be facilitated by presenting non-routine and open-ended contextual problems based on students' prior knowledge (Setiana, et al., 2019). Students need to be accustomed to contradictory and novel problems, so they can construct their thinking to seek truth and appropriate reasoning (Romberg, 2000).

STEM/STEAM Approach

STEM is an integration of four disciplines: science, technology, engineering, and mathematics, using an interdisciplinary approach and applied based on real-world context and problem-based learning. STEM education represents a teaching approach that combines these four disciplines to train individuals in developing various 21st-century skills. The aim is to enable them to provide solutions to challenges from an interdisciplinary perspective (Bybee, 2010). STEM education has been described as a standards-based, meta-discipline present at the school level, where all teachers, especially those in science, technology, engineering, and mathematics (STEM) fields, employ an integrated approach to teaching and learning. In this approach, discipline-specific content is not divided but rather addressed and treated as one dynamic, fluid study (Merrill, 2009).

In recent years, the term STEM has come to be affiliated with the field of science, technology, engineering, and mathematics education (Henriksen et al., 2019). However, once STEM was established as a handy way of referencing these four fields in a concise acronym, scholars urged a further expansion to include the arts—and thus was born the term STEAM (Robelen, 2011). Adding arts and design to the equation will transform STEM into STEAM (Liao, 2016). The notion of STEAM is an emerging discipline unique in its desire to provide a well-rounded approach to education (Rolling, 2016).

People think about STEM or STEAM in many different ways. In the field of education, they are the same approach and differ only in the number of disciplines integrated. STEM/STEAM approach incorporates the idea of transdisciplinary learning which is the idea that students learn through a true blending of the disciplines and that they are solving problems set in a real context (Quigley & Herro, 2016). Integrating the arts and sciences in educational settings is essential, as historical evidence shows that the most effective and innovative STEM practitioners draw on scientific and artistic knowledge and experience (Piro, 2010; Shlain, 1991; Simonton, 1988). In practice, however, the education sector has found it difficult to realistically integrate these disciplines

into a STEAM approach (Jolly, 2014). The essence of STEAM is not simply the application of art to science or vice versa. STEAM as an educational paradigm is broad and has enormous value in broadening perspectives on the intersection of art and STEM (Henriksen et al., 2019). On the other hand, (Jolly, 2014, 2016; Madden et al., 2013) state that the core of STEAM education lies in the interdisciplinary approach that celebrates the arts and sciences, among other disciplines, by engaging equally analytically, intuitively, logically, and aesthetically.

Research studies on enhancing critical thinking skills through STEM/STEAM approaches in mathematics education can be summarized into two important questions: (1) What is the distribution of research in terms of publication years and countries of researchers between 2018 - 2022?; (2) What are the best designs used in these studies in terms of research methodology, data collection instruments, instructional models, and types of interventions?

Method

Research Design

The methodology used is a Systematic Literature Review (SLR) with guidelines from Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). SLR is a method of gathering appropriate data on a topic that meets predetermined eligibility criteria (Mengist et al., 2020). This SLR is used to find main database articles in answering research questions. PRISMA establishes a standardized, peer-reviewed methodology that employs a guideline checklist to contribute to the revision process's quality assurance and replicability (Conde et al., 2020; Moher et al., 2015). The four main steps in PRISMA are identification, screening, eligibility, and inclusion. By following PRISMA guidelines, we could accurately search for the best practices in STEM/STEAM in mathematics education. The four main step in PRISMA are elaborated as follows:

Identification

The identification phase is carried out based on predetermined research questions. Search articles in online databases using keywords according to research questions. Keywords are used as a filtering tool on search engines in some indexed journals.

Table 1. The keywords

Keyword	Search terms
STEM or STEAM	(“STEAM” OR “STEAM approach” OR “STEAM Education” OR “science, technology, engineering, art, mathematics”)
Mathematics education	(“mathematics education” OR “mathematics”)
All keyword	(("STEAM" OR “STEM”) AND ("critical thinking skills" OR "critical thinking ability" OR "mathematical critical thinking") AND (“mathematical learning” OR “mathematical teaching” OR “mathematics education” OR “mathematics”))

Table 1 specifies the keywords used by researchers to find articles on search engines in several indexed journals. The author compiles a list of synonyms and alternative terms based on the most popular searches. The database used in this study includes three indexed journals, namely Springer, Eric, and Google Scholar. These four databases serve as a place to see the distribution of research on critical thinking skills in STEM/STEAM in mathematics education. Identification using search strategies with keywords on search engines produces 214 Springer-indexed articles, 88 Eric-indexed articles, and 17,300 Google Scholar-indexed articles. As a result, 17,602 journal articles have been classified at this stage.

Screening

In this phase, screening was carried out using the inclusion and exclusion criteria in Table 2. Articles identified in the previous identification phase were screened using the established inclusion and exclusion criteria.

Table 2. Inclusion and exclusion criteria

Inclusion criteria (IC)	Exclusion criteria (EC)
Publish since 2018 (last 5 years)	< 2018
Journal articles, conference proceedings	Non-journal articles, review journals, chapters in books, master dissertations, prefaces, opinion
Published in English language	Not published in the English language
Mathematics Education	Not research in mathematics education
Open access	Not open access

Table 2 is the inclusion and exclusion criteria for filtering articles based on publication time, language, the field of study and search access. The articles retrieved were only published in the last five years between 2018 and 2022. The data retrieved were journaled articles. No books, book chapters, were excluded in the selection. Furthermore, we only focus on English articles to minimize the possibility of difficulties in language translation. For the field of study, the articles taken are particular in mathematics education, and outside this field are excluded. Finally, we focus on open-access publications, not open-access journals are excluded. After the screening stage, 629 articles were identified for selection.

Eligibility

The feasibility phase is generated from articles relevant to the eligibility criteria. After the screening phase, articles screened through the inclusion and exclusion criteria are then identified for eligibility through re-screening using the eligibility criteria.

Table 3. Eligible criteria

Eligibility Criteria (EC)	
EC1	Studies in the field of mathematics education
EC2	Research methodology (qualitative, quantitative, mixed method, and R&D), not a systematic review
EC3	The abstract contains the main research keywords, namely STEM or STEAM and critical thinking
EC5	Research on students and teachers at all levels of education (elementary school, junior high, high school, and college students)

Table 3 is a guideline for selecting articles in the feasibility phase. Articles identified in the screening phase still contain many articles in other fields such as science, physics, and biology in the STEM/STEAM approach. Therefore, research articles outside the field of mathematics education are discarded. The title, abstract, and methodology are thoroughly reviewed to ensure that the articles comply with the criteria and research objectives. We screened articles by title and abstract containing keywords, as shown in Table 1. Furthermore, we focused on all research methodologies except SRL because they have similarities with our study. Finally, excellent articles are also viewed based on the research object. We chose research that studied students or teachers at all levels of education, not a literature review. As a result, 58 articles were identified in this phase.

Inclusion

The final phase of the PRISMA approach is the inclusion of articles that have undergone several screening stages. The inclusion stage of this article is carried out through an overall article review of eligible articles to determine which articles are selected as the primary literature. All answers to research questions must be available and relevant to the research objectives, including the research design, research practices, data collection method and the kind of research intervention. In this phase, duplicate removing is also carried out. The same article is selected from several data based. Articles that do not contain answers to the research questions that have been set will be discarded. In the final stage, it was determined that 21 articles were included in the primary literature data. PRISMA's stages in this study are shown through the flow diagram in Figure 1.

The PRISMA stages shown in Figure 1 establish articles as the primary literature for review based on research questions. Fifteen articles have been identified that are suitable for use. This number is minimal compared to the number of articles identified in the initial phase of 17,602. These data shows that during the last five years, there have been very few studies of critical thinking skills using STEM/STEAM approaches, specifically in

mathematics education. We will see how the research study was carried out in terms of the characteristics of the research, the methodology used, and the specific objectives of the research.

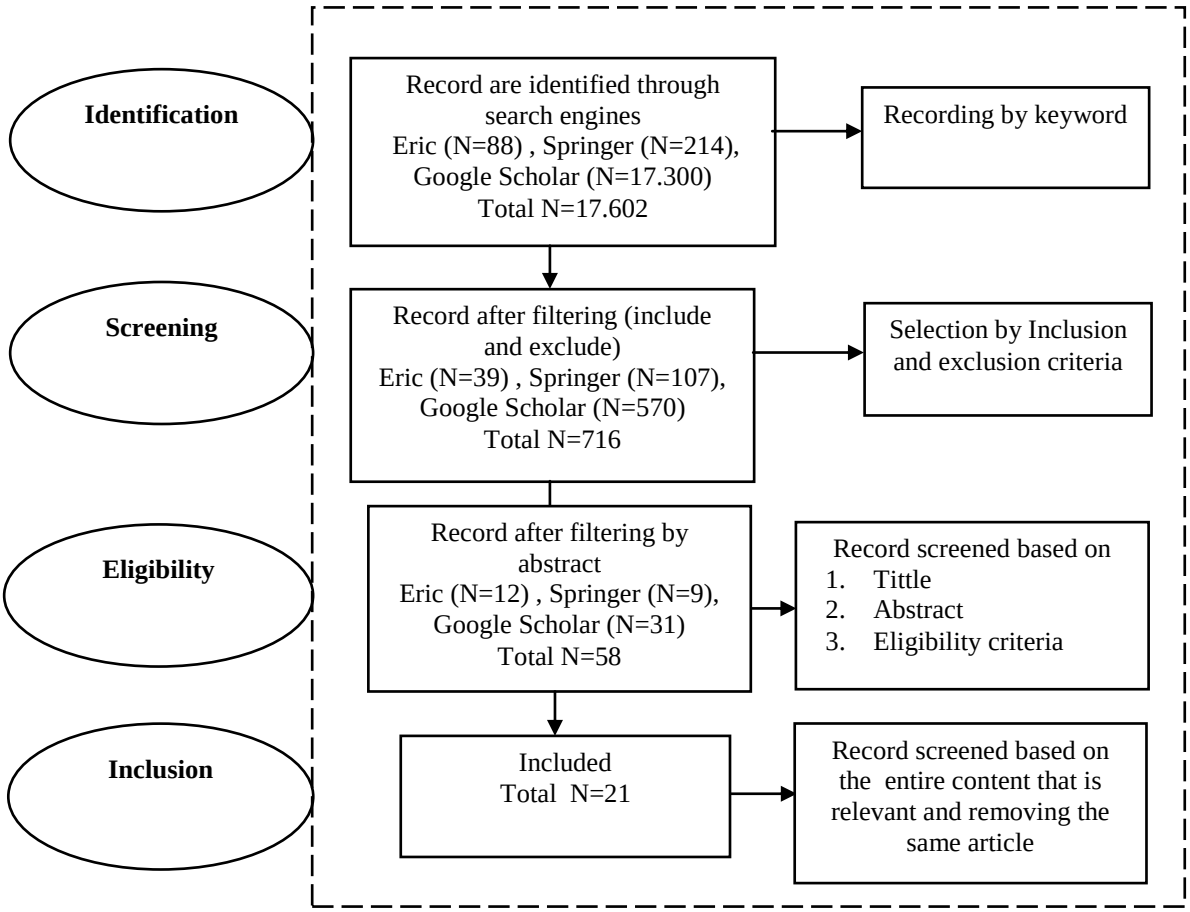

Figure 1. Flow diagram of prisam stage

Results and Discussion

Result

Data from the literature review results were obtained based on the six main questions in this study. The research questions focus on developing critical thinking skills in mathematics education through the STEM/STEAM approach. Research data can be an essential finding for educators and researchers to consider their studies on critical thinking skills in mathematics education and how STEM/STEAM is used to develop critical thinking skills.

Article Distribution

The distribution of article is grouped by year of publication, journal name and indexing, place of research, level of education of reseacrh participants. The mapping result of article distribution can be seen at Table 1. The results show that the largest distribution of articles was found in 2021.

Distribution of Publication Years in Literature Articles

The first research question focuses on the distribution of publication years from 2018 to 2022. This distribution of publication years will show the number of publications on critical thinking through STEM/STEAM studies in mathematics education over the past five years (Figure 2).

Table 1. Article distribution

No	Study	Publisher Journal Indexing	Journal or Proceeding Name	Country	Participants
1.	Singh et al., 2018	Eric	Internation Electronic Journal of Mathematics Education	Malaysia	Student at Senior High School
2.	Aldahmash et al., 2019	Scopus	Cogent Education	Saudi Arabia	Mathematics Teacher
3.	Priatna et al., 2020	Scopus	Journal for the Education of Gifted Young Scientists	Indonesia	Student at Junior High School
4.	Retnowati et al., 2020	Eric	Online Journal of Education and Teaching	Indonesia	Student at Junior High School
5.	Oktavia & Ridlo, 2020	Google Scholar	Journal of Primary Education	Indonesia	Student at Elementary School
6.	Suherman et al., 2021	Google Scholar	Journal of Advanced Sciences and Mathematics Education	Indonesia	Student at Senior High School
7.	Twiningsih & Elisanti, 2021	Google Scholar	International Journal of Emerging Issues in Early Childhood Education	Indonesia	Student at Elementary School
8.	Y. R. Kim et al., 2021	Scopus	International Journal of Education in Mathematics, Science, and Technology	USA	Student at Elementary School
9.	Bulu & Tanggur, 2021	Google Scholar	Al-Jabar: Jurnal Pendidikan Matematika	Indonesia	Student at University
10.	Safira et al., 2021	Google Scholar	THE 12th International Conference On Lesson Study (ICLS-XII)	Indonesia	Student at University
11.	Makhmudah et al., 2021	Google Scholar	Unnes Journal of Mathematics Education Research	Indonesia	Student at Senior High School
12.	Insani et al., 2021	Google Scholar	Journal of Physics	Indonesia	Student at Senior High School
13.	Astuti & Riswandi, 2021	Google Scholar	Asia-Pacific Forum on Science Learning and Teaching	Indonesia	Student at Elementary School
14.	Chang et al., 2021	Springer	Education Tech Research Dev	Taiwan	Student at Junior High School
15.	Kijima et al., 2021	Springer	International Journal of STEM Education	Japan	Female Youths
16.	Aydin Gürler, 2021	Eric	Participatory Educational Research	Turkey	Primary School Teacher
17.	Evangelisto, 2021	Eric	Journal of STEM Education	USA	College Teachers in Science, Technology, Engineering, and Mathematics.
18.	Siew, 2021	Eric	The 4th International Baltic Symposium on Science and Technology Education, BalticSTE2021	Malaysia	Student at Senior High School
19.	Wijayanti & Latiana, 2021	Google Scholar	Early Childhood Education	Indonesia	Student at Elementary School
20.	Pahrudin et al., 2021	Eric	European Journal of Educational Research	Indonesia	Student at Senior High School
21	Arini & Utomo, 2022	Google Scholar	International Journal of Multicultural and Multireligious Understanding	Indonesia	Mathematics Teacher

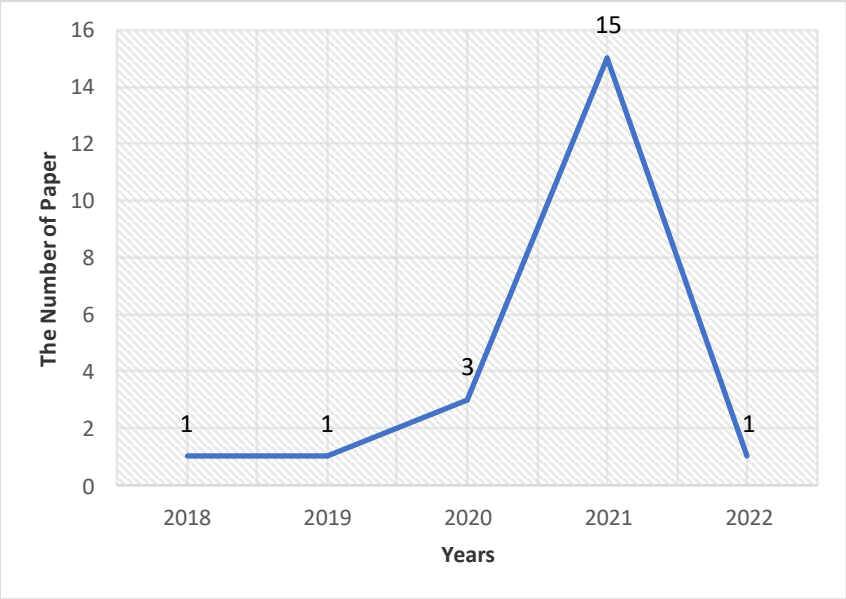

Figure 2. Distribution of publication years

Figure 2 The data shows that there has been an increase in research on critical thinking skills through STEM/STEAM from 2020 to 2021 and will decline again in 2022. Most research will be conducted in 2021, amounting to 71,42% of the existing research.

Distribution of Publication Countries in Literature Articles

The results that focus on geographical distribution show the contributions of researchers from different countries who study critical thinking skills in STEM or STEAM approaches to mathematics. The results show a distribution in the affiliation of the first author. Most of the research was conducted in the country of origin of the first author.

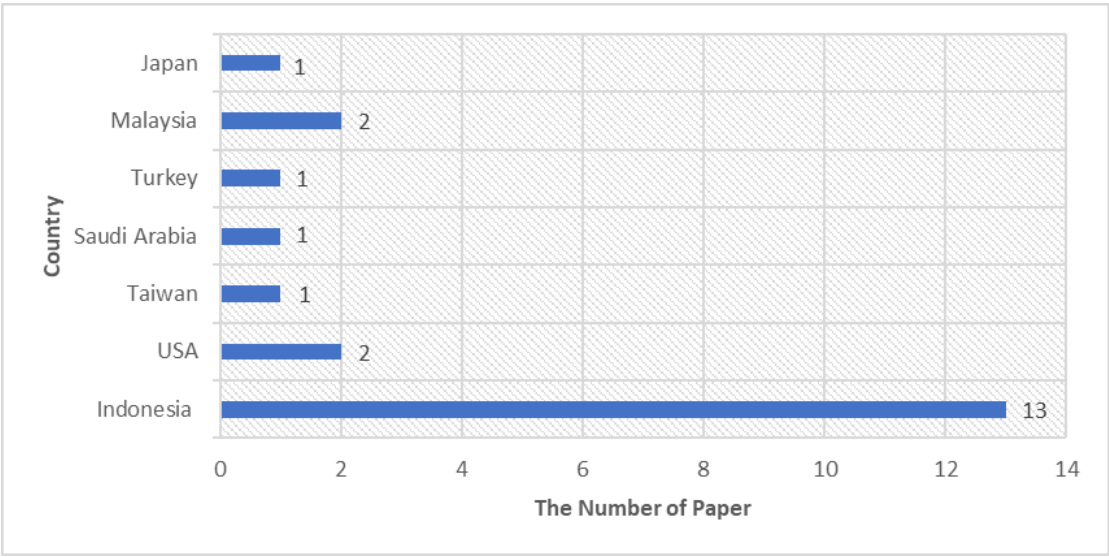

Figure 3. Author's country of affiliation

Figure 3 shows how the contribution of researchers by country of affiliation. Only seven countries have studied critical thinking skills in the STEM/STEAM approach to mathematics in the last five years. This number of countries is still very small when compared to the number of countries in the world that should have the potential to develop the critical thinking skills of its people through STEM/STEAM-based education. This study is still of low interest. Indonesia has the most significant number of authors, with 61,90% contributing to this study, and other countries still need more interest.

Research Methodologies in Literature Articles

One of the essential factors in research is research design as a framework for research methods and instrumen to achieve the researcher's goals. The research design determines how the researcher's thinking style determines a suitable way of developing critical thinking skills with STEM/STEAM and type of data collection tool to improve Critical thinking ability through STEM (STEAM) used researcher to collected data.

Table 4. Types of method and instrument on research design

Method	Study	Instrument
Quantitative	Suherman et al., 2021	Critical thinking tests
	Bulu & Tanggur, 2021	Critical thinking tests
	Astuti & Riswandi, 2021	Critical thinking tests
	Chang et al., 2021	Critical thinking tests, rubrics for evaluating the STEM project work, and the collaboration tendency, critical thinking awareness
	Aldahmash et al., 2019	Questionnaire
	Aydin- Gurler, 2021	Critical thinking scales
	Pahrudin et al., 2021	Critical thinking tests
	Singh et al., 2018	
Qualitative	Kim et al., 2021	Critical thinking tests
	Evangelisto, 2021	Interview sheets
	Siew, 2021	Open-ended questions; focus group observation and interviews
	Wijayanti & Latiana, 2021	Interview and observation sheets
Mix method	Makhmudah et al., 2021	Critical thinking tests
	Kijima et al., 2021	Pre- and post intervention surveys
	Oktavia & Ridlo, 2020	questionnaire, critical thinking tests
Development	Priatna et al., 2020	Assessment of content validity, face validity, and construct validity
	Twiningsih & Elisanti, 2021	Media validation sheet, a teacher response questionnaire, a student observation sheet, and a student learning result sheet
	Arini & Utomo, 2022	Expert validation questionnaire and teacher questionnaires
	Safira et al., 2021	Observations sheets
	Insani et al., 2021	Observations sheets
	Retnowati et al., 2020	Critical thinking tests

Table 4 shows the research design and instruments used to develop critical thinking skills with a STEM/STEAM approach. This type of quantitative method is the most widely used compared to other types. Furthermore, development method and experimental design is used second most. The percentage of the use of the type of research method is quatitative 38.09%, development 28.57%, qualitative 19.05% and mix method 14.28%.. The most widely used type of research instrument is the critical thinking test. The test is designed to measure the critical thinking skills of participants and its use is seen not only in quantitative methods but also in other methods such as qualitative, mixed methods and development.

Type of Research Practice in Literature Articles

The results of the review reveal that there are many research practices used as models or strategies by researchers. Table 5 reveals 13 different types of practices used by the researchers reviewed. Two articles use project-based learning as a best practice and one for each type of practice. In addition, two articles need to mention the types of research practices used, and most of the research practices in STEM/STEAM use project-based approaches and technology applications. These results indicate that project-based learning is the most suitable learning model for use in the STEM/STEAM approach, while other models that vary are more directed at the purpose of identifying critical thinking skills both cognitively and effectively (Sun Han et al., 2014; Priatna et al. al., 2020; Tseng et al., 2013). There were 6 out of 21 articles that did not use models or strategies integrated with the STEM/STEAM approach.

Table 5. Research practices

Research Practices	Study
Project-based learning	Bulu & Tanggur, 2021, Oktavia & Ridlo, 2020
Technological integration	Suherman et al., 2021
Colored two-dimensional figure mixing	Twiningsih & Elisanti, 2021
Android-based application	Arini & Utomo, 2022
Robotic coding activities	Y. R. Kim et al., 2021
Peer Assessmentt Facilitated	Chang et al., 2021
Blended learning	Safira et al., 2021
Problem-based learning	Makhmudah et al., 2021, Singh et al., 2018
Inquiry learning	Pahrudin et al., 2021
Learning Community	Insani et al., 2021
Design Thinking Workshop	Kijima et al., 2021
Profesional development program	Aldahmash et al., 2019
Mentee Outreach Program	Siew, 2021
Not mentioned (non-practices)	Priatna et al., 2020, Astuti & Riswandi, 2021, Retnowati et al., 2020, Aydin -Gürler, 2021, Evangelisto, 2021, Wijayanti & Latiana, 2021

The Kind of Intervention in Literature Articles

Intervention in this research question is defined as the main activity of the stated research objectives. Many types of interventions are found in assessing critical thinking skills through STEM/STEAM in mathematics education.

Table 6. The kind of intervention of the paper

Activities	Study
Developing of learning model	Priatna et al., 2020, Safira et al., 2021
Comparing of critical thinking skills between genders	Suherman et al., 2021
Conducting educational interventions for adolescent female youths' perceptions of STEM topics	Kijima et al., 2021
Developing of media	
Developing the colored two-dimensional figure mixing media	Twiningsih & Elisanti, 2021
Developing android based application	Arini & Utomo, 2022
Developing lesson plans, worksheets, and instrument tests of critical thinking ability	Insani et al., 2021
Developing of rectangular module	Retnowati et al., 2020
Conducting of Robotics coding activities	Kim et al., 2021
Using of Web e-learning School	Suherman et al., 2021
Analyzing the implementation of STEM approach in learning mathematics	Astuti & Riswandi, 2021, Wijayanti & Latiana, 2021, Pahrudin et al., 2021, Oktavia & Ridlo, 2020, Singh et al., 2018, Bulu & Tanggur, 2021
Identifying of peer assessment – facilitated STEM (PA-STEM) approach	Chang et al., 2021
Identifying State of prediction of the critical thinking dispositions	Aydin Gürler, 2021
Describing community college teachers' method and techniques in STEM disciplines	Evangelisto, 2021
Integrating STEM through Short professional development program	Aldahmash et al., 2019
Tackling the STEM learning gap	Siew, 2021

Table 6 shows that 12 types of interventions can be identified from 21 literature articles. The highest type of intervention, at 28.57%, was through Analyze the implementation of STEM approach in learning mathematics. Some researchers tried to develop critical thinking skills through various media such as the coloured two-dimensional figure mixing media, android, lesson plans, worksheets, instrument tests, and modules. Various

interventions have been used by researchers to develop or analyse critical thinking skills in mathematics education. Another exciting type of intervention is through robotic coding and peer assessment activities to see how this critical thinking ability is achieved.

Discussion

The research findings show that in the last five years (2018-2022), research examining critical thinking skills through STEM/STEAM in mathematics education still needs to be made public. Of the 17,602 articles identified through search keywords in three large databases, namely Eric, Springer, and Google Scholar, only 21 were identified as relevant to the purpose of this study. The low number of relevant articles relates to specific research topics with three main keywords: ritical thinking, STEM/STEAM, and mathematics education. Based on the findings, most of the research in this study was conducted in 2021. This data has increased since 2020 and decreased again in 2022. The significant increase in research in 2020 and 2021 was investigated due to the increasing popularity of STEM/STEAM for enhancing 21st-century skills. STEM is a critical issue recognized internationally as a foundation for economic growth and advancing skills people need in the 21st century (Chai, 2019; Maass et al., 2019). Especially in mathematics education, the results show that integrating STEM into learning can improve the students' accomplishment in algebra, geometry, and probability (Han et al., 2016). The decline in publications in 2022 is that most of the STEM/STEAM research in mathematics education does not lead to developing critical thinking. Most of the research was conducted to examine the perceptions of teachers and prospective mathematics teachers about STEM (Pathoni, Ashyar, Maison & Huda, 2022; Hoon et al., 2022; Rahman et al., 2022). Hoon et al. (2022) say that the importance of STEM contrasts with their concerns about teachers' knowledge and readiness to implement STEM. Identifying and evaluating the perceptions of teachers and prospective teachers regarding their knowledge, readiness, experience, and efforts to practice STEM will become more important for research in 2022.

Regarding the distribution of the author's countries and the same time the research was conducted, the findings show that in the last five years, only five countries have been interested in conducting critical thinking studies through STEM/STEAM in mathematics education. Indonesia has the highest number of studies compared to other countries. Indonesian researchers' interest in developing critical thinking skills through STEM/STEAM is based on the low mathematics achievement of Indonesian students in PISA (Suherman et al., 2021). Based on PISA results in 2018, 72% of Indonesian students are considered low achievers in mathematics (Schleicher, 2019). PISA results become a reference for educators in Indonesia to improve the quality of Indonesian students' mathematical abilities in various ways, one of which is through the STEM/STEAM approach. The research results show that STEM learning can improve students' critical thinking skills (Suherman et al., 2021). STEM step will provide students with new information on what has been observed, allowing them to analyze and think critically (Borrego & Henderson, 2014; Hobbs et al., 2018; Kusumah, 2019). Other countries such as the USA, Taiwan, Saudi Arabia, Turkey, and Malaysia have made small contributions to this study. The small number of countries that contribute shows the need for more diversity of countries to study critical thinking through STEM/STEAM. Even the USA, as a STEM pioneer country, only contributes a little to studying critical thinking skills through STEM/STEAM. Researchers from the USA conducted research through robotic coding activities in math class. Robotic coding activities have transferability implications that afford STEM learning access and opportunities for students to develop mathematical reasoning and critical thinking skills that are operable in a coding environment (Kim, 2012).

Other findings regarding the research methodology used in the research articles reviewed, most researchers use quantitative research, followed by Research and Development (R&D). Meanwhile, qualitative and mixed-method research was used by a small number of researchers. R&D research is mainly used by Indonesian researchers, including developing learning tools such as lesson plan sheets and student worksheets based on the STEM approach to improve students' critical thinking skills (Insani et al., 2021). The existence of various research designs also influences the type of data collection tool used. The findings show that there are seven types of data collection tools or research instrument used yaitu critical thinking tests, questionnaire, critical thinking scales, critical thinking awareness, interview sheets, open ended questions, observations sheets, interview sheets, survey, assesment of validity, collaboration tendency and STEM project work. Test instruments are this study's most used types of data collectors. The test instrument was used to measure and determine the achievement of critical thinking skills using the STEM approach as a cognitive aspect of students. For the affective aspect, a questionnaire was used to find student responses to the learning being carried out (Insani et al., 2021). Identifying critical thinking skills can use tests as quantitative data, and perceptions about critical thinking can use questionnaires, peer assessments and interview sheets as qualitative data. Several researchers (Arini & Utomo, 2022; Insani et al., 2021; Retnowati et al., 2020; Twiningsih & Elisanti, 2021) use

validation sheets to validate product development. In addition, observation sheets and documentation tools are used to collect research data during the research process.

This study also revealed that many types of research practices are used to examine critical thinking through STEM/STEAM in mathematics education. Of the 13 types of research practices, the project-based learning method is used the most. However, many of them do not use research practices in their research including (Priatna et al., 2020; Astuti & Riswandi, 2021; Retnowati et al., 2020; Aydin- Gurler, 2021; Evangelisto, 2021), (Wijayanti & Latiana, 2021). These results align with the results of a literature review by (Pahmi et al., 2022), which examined the influence of STEM in mathematics education. Fahmi found that from 2012 – 2021, project-based learning was the most widely used model, namely, 43% of the total research sample. Project-based learning is a dynamic learning approach where students actively explore real-world problems and challenges and gain more profound knowledge (Bell, 2010; Kricsfalusy et al., 2018; Wiek et al., 2014). The main characteristic of this project-based learning is directed learners and engages learners in finding the concept of discipline through a constructive investigation (Gülbahar & Tinmaz, 2006; Yadav et al., 2011). Project-based learning is very suitable for the STEM/STEAM approach because it can increase student interest in the studied field. In addition, project-based learning can improve critical thinking skills as a 21st-century skill. The characteristics of project-based learning follow the 21st-century learning paradigm, and current research shows that projects can increase students' interest in STEM studies. The many types of practice used in literature articles indicate that critical thinking skills can be improved through various practices or research models. This type of practice also fits the characteristics of STEM/STEAM as an interdisciplinary approach.

Finally, findings on the types of interventions carried out by researchers show results as varied as the types of practice. This type of intervention refers to the specific goals of the research and the way the researcher achieves his goals. This intervention is described through research activities, such as comparing critical thinking skills between the sexes (Suherman et al., 2021). Sherman stated that there were differences in the ability to think critically mathematically between male and female students in STEM learning. Female students have higher critical thinking skills than male students. In another study,(Aldahmash et al., 2019) developed a teacher profession program by integrating STEM into it. Aldahmash analyzes math and science teachers in Saudi Arabia concerning the way teachers teach STEM. This short STEM program is expected to improve critical, creative, and analytical thinking skills in Saudi Arabian teachers. The most widely used type of intervention was development activity by 46.7% of the research literature sample. Development activities in this study include the development of learning models, media, and teacher professional programs. This development research trend is mainly carried out in Indonesia (Arini & Utomo, 2022; Insani et al., 2021; Priatna et al., 2020; Retnowati et al., 2020; Safira et al., 2021; Twiningsih & Elisanti, 2021). The trend of this development intervention is based on the popularity of STEM in Indonesia, which is still growing in the last five years. The various identified interventions show various ways and research activities that can be carried out to examine critical thinking through STEM/STEAM in mathematics education. Researchers, especially researchers in mathematics, can use this finding as an alternative to developing various 21st-century skills through STEM/STEAM.

Conclusion

STEM has become a popular approach in the last five years specially on mathematics education, but only a few have been explicitly identified in the study of critical thinking. Research on critical thinking through STEM/STEAM in mathematics education from 2018 to 2022 was mainly conducted in 2021. There was a significant increase from 2020 and a sharp decrease in 2022. The most primary authors who study critical thinking through STEM/STEAM come from Indonesia, and contributions are evenly distributed from the USA, Taiwan, Saudi Arabia, Turkey, and Malaysia. The most widely used research methodology in this finding is development research or R & D and quantitative research. This methodology aligns with the types of data collection tools the researchers used. They used a variety of test instruments and questionnaires to see the results of the study. The SLR results show the types of interventions from each country as a typical way to assess mathematics critical thinking skills through STEM/STEAM. The best practice for improving learner's mathematical critical thinking skills in STEM/STEAM is Project-Based Learning (PBL). However, this practice is not used by many development researchers. The authors find distinctive features in the interventions used by researchers to improve the critical thinking of learners from each country. The most common intervention was an analysis of the implementation of the STEM/STEAM approach in Indonesia. Many Indonesian researchers also developed learning models and media. Other countries focused more on computer-based activities, developing community programs, and identifying participants' perceptions of critical thinking. These differences give each country its own characteristics in improving and identifying the critical thinking skills of its people.

These differences in practices and interventions can also provide alternatives for researchers in their research on critical thinking through the STEAM approach.

Recommendations

The SRL findings illustrate how each researcher from different countries has their own characteristics to analyze and develop mathematical critical thinking skills for their communities through the STEM/STEAM approach. Therefore, we recommend researchers who are interested in this study try to conduct research using the best practices and interventions used by other researchers outside your country. It will provide new nuances, experiences, and interesting results if we try a new things outside the customs of our country. We can also see different result from our reseacrh with others.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the authors.

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