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Abstract

Critical thinking is one of the 4C skills needed in 21st century education. This is the reason for the need to conduct a review to find an effort to improve critical thinking skills, especially in education. A relevant strategy in this effort is integrating STEM (Science, Technology, Engineering, and Mathematics) into the learning process. A systematic review related to critical thinking with STEM integrated learning was conducted in this study. In this study, a review of related articles published in the period 2020-2025 was conducted. The articles reviewed in this study came from various international journals in Crossref, Scopus, and Google Scholar with relationship analysis assisted by VOSViewer software. The results of this literature review show the influence of STEM-integrated learning on students' critical thinking skills. It is concluded that it is necessary to develop other learning innovations that involve STEM integration in it by paying attention to indicators of critical thinking skills in each learning activity.

Introduction

The rapid development of the times poses challenges in all aspects of life, one of which is education. In order to produce a generation that is skilled in responding to world developments and adapting to them, a quality education system is needed in a country. Education is one of the goals in the SDGs which is specifically contained in the 'Quality of Education' element and is one of the benchmarks for a country in regulating their education system (Mduwile & Goswami, 2024). Therefore, a nation makes various efforts in improving and innovating various strategies in order to create quality learning in various fields of science. Mathematics is one of the fields of science studied at all levels of education in a country (Siregar et al., 2024). Mathematics learning is important to form various individual skills such as the ability to think logically, critically, analytically, and systematically (Mytra et al., 2023). In achieving quality education, especially in the 21st century, competency standards have been studied, called the 4Cs, where one of the elements is critical thinking skills (Arsanti et al., 2021).

The ability to think critically as one of the current needs is defined as a person's ability to analyze, evaluate, and conclude an information or argument objectively and rationally (Rahardhian, 2022) Where Ennis (2011) It also mentions several indicators in measuring critical thinking skills, including basic clarification, basic support,

inference, advanced clarifications, as well as strategy and tactics. The ability to think critically will encourage students to not only accept the knowledge given but also to question various related things and process their knowledge with various other sources (Ariefah et al., 2025). In the context of mathematics learning, students with good critical thinking will be able to understand concepts in depth by developing independent thinking through various existing information to then be used in making the right decisions when faced with a complex problems (Hacioglu & Gulhan, 2021). The characteristics of individuals with the critical thinking skills that have been described can equip themselves in the process of adapting to the increasingly developing world situation. This shows the urgency of developing critical thinking skills, especially in mathematics learning.

Although it is stated that it is important to have, the existing facts show that the critical thinking skills of students in Indonesia are still low. Based on data of OECD (2023), As a result of the latest publication of PISA (Programme for International Student Assessment) in 2022, Indonesia achieved an average mathematics score of 366 where this figure is in the range of the level 1 category, while the minimum level category for the indication of critical thinking skills is at level 4 with a minimum score of 545. This shows that the fulfillment of critical thinking skills in Indonesia is still very low. Further data from PISA 2022 also shows that the total percentage of students in Indonesia who have good critical thinking skills is estimated to be only 0.5%, this international data clearly means that the lack of critical thinking skills in Indonesia is a serious problem. Supporting facts in the field were also found by several studies related to students' critical thinking skills that are still low in Indonesia, especially at the secondary school level (Siburian et al., 2023; Syafitri et al., 2024;Inggriyani & Fazriyah, 2018) So based on these findings, it can be clearly concluded that the fulfillment of the characteristics of students' critical thinking skills in Indonesia is still low and efforts are needed to overcome this problem.

STEM integration can be an alternative in an effort to improve students' critical thinking skills, especially in mathematics learning. STEM can be interpreted as a learning approach that applies the concepts of four disciplines, namely Science, Technology, Engineering, and Mathematics in an applicative manner (Suwardi, 2021). STEM integrated mathematics learning can be packaged in a variety of ways, either simply bringing STEM into mathematical concepts or combining it with various other innovations such as certain learning models and relevant learning media or instruments. The characteristics of STEM integrated mathematics learning are not only focused on mastery of the material, but also emphasize real-life concepts applied to abstract mathematical concepts STEM integrated mathematics learning can be packaged in a variety of ways, either simply bringing STEM into mathematical concepts or combining it with various other innovations such as certain learning models and relevant learning media or instruments. The characteristics of STEM integrated mathematics learning are not only focused on mastery of the material, but also emphasize real-life concepts applied to abstract mathematical concepts STEM integrated mathematics learning can be packaged in a variety of ways, either simply bringing STEM into mathematical concepts or combining it with various other innovations such as certain learning models and relevant learning media or instruments. The characteristics of STEM integrated mathematics learning are not only focused on mastery of the material, but also emphasize real-life concepts applied to abstract mathematical concepts (Guerra, 2024) STEM integrated mathematics learning can support the creation of meaningful learning because students use their knowledge in daily life to solve the given math problems. Studies show that students who engage in STEM learning tend to have better critical thinking skills compared to students who follow

conventional learning, this is due to the characteristics of student-centered learning, where students become active actors in finding solutions, not just recipients of information (Mater et al., 2020)

Based on this description, the purpose of this systematic review is to examine the findings of existing relevant research related to STEM integrated learning on critical thinking skills from 2020-2025. In addition, this study was conducted to present a broader description related to the influence of STEM integration on students' critical thinking skills. There are several steps in a systematic process. First, collecting various empirical studies based on criteria. Then, select research based on criteria. Finally, synthesize all relevant information from previous research and explain the current status of the research as well as the effect size of the approach used.

Method

Research Goal

The objectives of this research include (RG 1) identifying research trends regarding critical thinking skills in STEM integrated mathematics learning in the last 5 years, (RG 2) describing whether STEM integrated mathematics learning can develop critical thinking skills.

Research Design

The method in this study uses Systematic Literature Review (SLR). According to Hadi et al (2020) Systematic Literature Review is a method for searching, reviewing, and summarizing several studies related to the topic being discussed. Figure 1 shows the steps in this study. These steps include compiling research goals, searching for articles with the keywords 'critical thinking skills in STEM integrated learning' published in 2020-2025. Data is obtained from Google Scholar, Crossref, and Scopus databases with the help of Publish or Perish using these keywords. The database was chosen because it is the most frequently used database in scientific papers. Conduct a selection of all articles that appear according to the keywords based on the criteria reviewed (starting from the title, abstract, and duplication of the title, as well as the exclusion inclusion criteria in the three databases). After the selection process, articles that meet the criteria will be assessed for data quality and data extraction. Followed by the last step, namely the synthesis process used to determine the results of the research. Table 1 describes the inclusion and exclusion criteria provisions related to this systematic review.

Table 1. Inclusion and Exclusion Criteria

Inclusion	Exclusion
Articles published in 2020-2025	Articles published outside the year range
Articles published in national and international journals	Articles that does not use Indonesian or English
Articles that are in line with the topic of critical thinking skills in STEM integrated learning	Articles that are not in line with the topic of critical thinking skills in STEM integrated learning
Quantitative, qualitative, mixed method, or literature review research methods	The research method is not quantitative, qualitative, mixed method, or literature review

Inclusion and exclusion criteria are used to determine whether or not the data obtained in SLR research are suitable for use. This criterion is used as a guideline in the selection of research on critical thinking skills in STEM integrated learning in articles and proceedings published in journals and conferences. In the initial search, there were 1200 titles found, then after going through several stages of selection starting from the selection of title suitability, abstracts, duplication of titles, and the year of publication of the article which was determined to be 20 titles in the end.

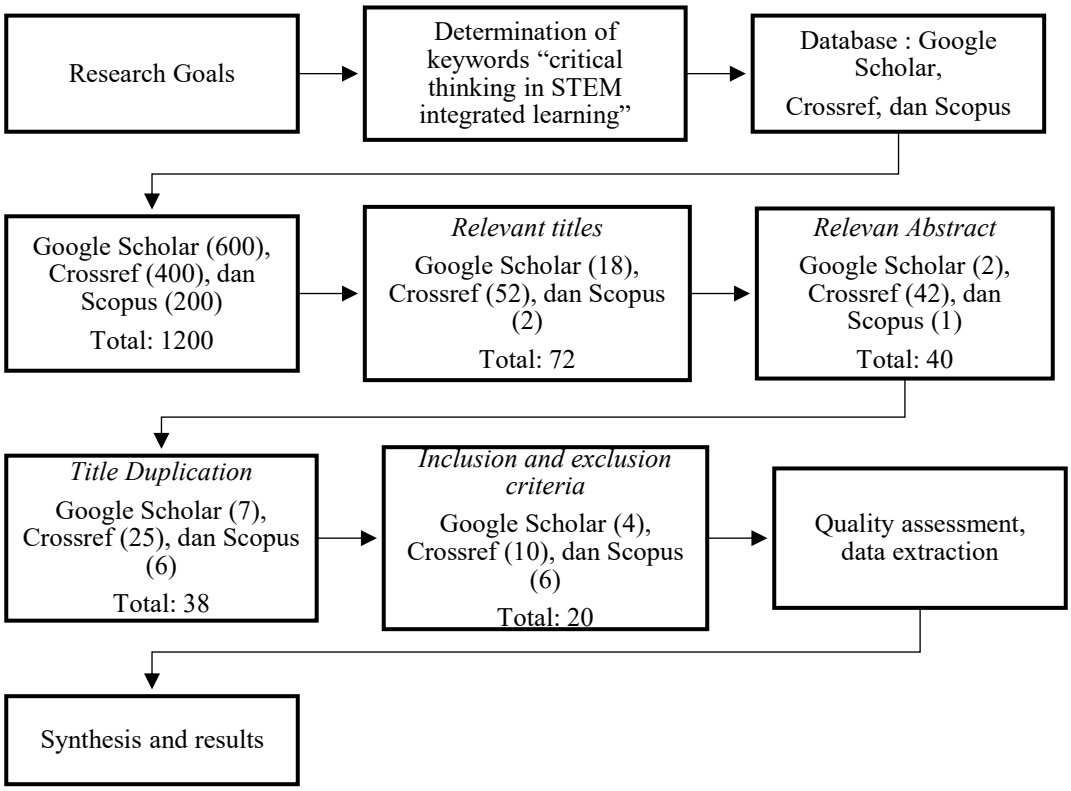

Figure 1. Steps in Systematic Review Research

Results and Discussion

Based on the SLR stages that have been carried out, 20 articles have been processed from Crossref as many as 10 articles, Scopus as many as 6 articles and Google Scholar as many as 4 articles. Where the methods used in the 20 articles are in the form of quantitative research (9 titles), qualitative (1 title), mixed method (5 titles), RND (3 titles), and literature review (2 titles). The articles were obtained with the help of Publish or Perish. The data of 20 article identities are presented in Table 2, as well as the research results of the 20 selected titles are listed in Table 3.

Table 2. Related Literature Identity Data

Author, year	Article Title	Journal Identity	Type of Research (Country)
(Asigigan &	The Effect of Gamified STEM Practices	International Journal	Mixed method

Author, year	Article Title	Journal Identity	Type of Research (Country)
Samur, 2021)	on Students' Intrinsic Motivation, Critical Thinking Disposition Levels, and Perception of Problem-Solving Skills	of Education in Mathematics, Science and Technology.	(Turkey)
(Hebebci & Usta, 2022)	The Effects of Integrated STEM Education Practices on Problem Solving Skills, Scientific Creativity, and Critical Thinking Dispositions	Participatory Educational Research (PER)	Quantitative (Turkey)
(Hacioglu & Gulhan, 2021)	The Effects of STEM Education on the Students' Critical Thinking Skills and STEM Perceptions	Journal of Education in Science, Environment and Health (JESEH)	Mixed method (Turkey)
(Allanta & Puspita, 2021)	Analysis of students' critical thinking skills and self-efficacy: The impact of PjBL - STEM on ecosystem materials	Jurnal Inovasi Pendidikan IPA	Quantitative (Indonesia)
(Hasanah et al., 2021)	Implementation of Problem Based Learning Model Combined with STEM-Based LKPD to Improve Critical Thinking Skills on Environmental Pollution Materials	Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)	Quantitative (Indonesia)
(Setyawati et al., 2022)	Improving Mathematical Critical Thinking Skill through STEM-PjBL: A Systematic Literature Review	International Journal of Research in STEM Education (IJRSE)	Literature Review (Indonesia)
(Parno et al., 2021)	The effectiveness of STEM approach on students' critical thinking ability in the topic of fluid statics	Journal of Physics: Conference Series	Quantitative (Malaysia)
(Widayanti & Juhji, 2023)	Developing STEM Based PowToon Animation Videos to Enhance Critical Thinking Skills in Elementary School Students	The Journal of Integrated Elementary Education	Research and development (Indonesia)
(Azeem & Rasool, 2024)	Effectiveness of STEM-based Approach on Enhancing Critical Thinking Skill of Elementary School Studentsin Faisalabad	Pakistan Languages and Humanities Review (PLHR)	Quantitative (Pakistan)
(Gencer & Dogan, 2020)	The Assessment of the Fifth-Grade Students' Science Critical Thinking Skills through Design-Based STEM Education	International Journal of Assessment Tools in Education	Quantitative (Turkey)
(Yaki, 2022)	Fostering Critical Thinking Skills Using Integrated STEM Approach among Secondary School Biology Students	European Journal of STEM Education	Quantitative (Nigeria)

Author, year	Article Title	Journal Identity	Type of Research (Country)
(Linh et al., 2022)	Developing critical thinking of students through STEM educational orientation program in Vietnam	Journal of Physics: Conference Series	Qualitative (Thailand)
(Mater et al., 2020)	The effect of the integration of STEM on critical thinking and technology acceptance model	Educational Studies	Mixed method (Palestine)
(Guerra, 2024)	The contribution of critical thinking to STEM disciplines at the time of generative intelligence	STEM Education	Literature review (Italy)
(Reynders et al., 2020)	Rubrics to assess critical thinking and information processing in undergraduate STEM courses	International Journal of STEM Education	Research and development (USA)
(Ariefah et al., 2025)	Description of Junior High School Students' Critical Thinking Skills Using STEM-PBL-Based EModul	Jurnal Pendidikan Tambusai	Mixed method (Indonesia)
(Langi, 2025)	Application of STEM Integrated Problem Based Learning Model to Critical Thinking Skills in Newton's Law Material	Edu Cendikia: Jurnal Ilmiah Kependidikan	Quantitative (Indonesia)
(Topsakal et al., 2022)	The Effect of Problem-based STEM Education on the Students' Critical Thinking Tendencies and Their Perceptions for Problem Solving Skills	Science Education International	Mixed method (Turkey)
(Antunes et al., 2023)	A Dynamic STEM-Driven Approach through Mobile Robotics to Enhance Critical Thinking and Interdisciplinary Skills for Empowering Industry 4.0 Competencies	Technologies 2023	Research and development (Portugal)
(Rizki & Suprapto, 2024)	Project-Oriented Problem-Based Learning Through SR-STEM to Foster Students' Critical Thinking Skills in Renewable Energy Material	Journal of Science Education and Technology	Quantitative (Indonesia)

Table 3. Data Results from Literature Research Related to Critical Thinking in STEM Integrated Learning

Author, year	Research Results
(Asigigan & Samur, 2021)	Results show that gamified STEM practices positively and significantly improve students' critical thinking disposition, do not have a significant difference in students' perceptions of problem-solving skills, and positive effect on student' motivation,
(Hebebci & Usta,	the most integrated STEM education application has been effective in developing

Author, year	Research Results
2022)	students' problem-solving skills, , scientific creativity, and critical thinking skills based on the descriptive test and ANCOVA test
(Hacioglu & Gulhan, 2021)	STEM education developed students' critical thinking skills and STEM perceptions positively and also it had indirect effects on their career awareness.
(Allanta & Puspita, 2021)	The results showed that experimental class's average pre-test and post-test scores improve for each indicator, from 60.86 to 81.22, also the N-Gaintest was 0.55 or 31%. furthermore the average self-efficacy score of experimental class was 93% within the excellent category. Therefore, the PjBL model with the STEM approach influenced the tenth-grade students' critical thinking skills and self-efficacy on ecosystem learning materials
(Hasanah et al., 2021)	The results showed that the critical thinking skills obtained was 0.93, with an increase in high category. the independent sample t-test obtained Sig. (0,000) <α (0.05) then it is suggested that there are differences in the critical thinking skills between experimental and control class. The implementation of PBL learning model combined with STEM-based LKPD can improve students' critical thinking skills on environmental pollution material in class 10th SMA Negeri Bireuen Regency.
(Setyawati et al., 2022)	the use of STEM-PjBL had a positive and significant impact on the critical thinking skills of students in each educational unit, the use of STEM-PjBL can help students improve their mathematical critical thinking skills
(Parno et al., 2021)	This research found that both models were effective in building students' critical thinking skills. Furthermore, the enhancement in students' skill was affected by the different initial state and the different treatment of learning. STEM learning model resulted in significantly better critical thinking in students than learning cycle model. However, STEM learning model was more effective than learning cycle.
(Widayanti & Juhji, 2023)	PowToon animation with the STEM approach received positive feedback from experts. When the topics were presented through this animation, a significant improvement in the students' critical thinking abilities was observed.
(Azeem & Rasool, 2024)	STEM-based instruction dramatically enhanced critical thinking. STEM education gives young peoplethe critical thinking skillsthey need to succeed in today's complicated, interconnected world,producing workforce and informed citizens
(Gencer & Dogan, 2020)	Comparing the pre and post applications of instruments in the study group indicated that STEM modules improved the students' science critical thinking skills such as interpretation, analysis, and inference. In this respect, developing and validating instruments to assess the integrated critical thinking skills will contribute to the empirical examination of this construct within the context of school science learning.
(Yaki, 2022)	The findings of the within-group comparison show that the experimental group shows a significant difference between pre-test and post-test with a larger effect size compared to the control group. There are difference in students' critical thinking skills of inference, recognizing assumption, deduction, interpretation, and evaluating arguments. Therefore,

Author, year	Research Results
	it can be concluded that an integrated STEM approach was more effective in enhancing students' critical thinking skills.
(Linh et al., 2022)	The results show the development of critical thinking of students through STEM activities and some superior suggestions for using STEM activities to motivate critical thinking of students in high school.
(Mater et al., 2020)	The main findings revealed that the experimental group students' attitudes were positively changed towards learning science, technology and maths. Students were able to solve real-life problems, learn complex concepts and apply them. It was recommended to use STEM-based activities in schools in a more systematic way.
(Guerra, 2024)	The result of this reflection indicates that critical thinking, guided by philosophy, can play a crucial role in STEM, especially concerning the Post-Normal Science model, in which the construction of scientific knowledge leaves the academy
(Reynders et al., 2020)	As part of the Enhancing Learning by Improving Process Skills in STEM (ELIPSS) Project, rubrics were developed to assess these two skills in STEM undergraduate students' written work. The rubrics were implemented in multiple STEM disciplines, class sizes, course levels, and institution types to ensure they were practical for everyday classroom use. The ELIPSS rubrics allowed instructors to explicitly assess the critical thinking and information processing skills that they wanted their students to develop in their courses
(Ariefah et al., 2025)	Students can formulate the subject matter well, be able to express and manage facts, be able to make logical arguments well, be able to draw conclusions, and be able to evaluate well. This indicates the fulfillment of all indicators of critical thinking ability in students.
(Langi, 2025)	The study results indicate a significant difference between the experimental and control classes, so it is included in the moderate influence category. Thus, the integrated PBL approach with STEM effectively improves students' critical thinking skills in Newton's Law material.
(Topsakal et al., 2022)	the problem-based STEM education created a positive effect as cognitive maturity and innovativeness in the students' feelings, thought and behaviours. According to these results, it can be claimed that STEM education is highly effective in developing the skills that are expected from individuals in the 21st century such as problem-solving, critical thinking, social interaction.
(Antunes et al., 2023)	Robotic educational resources are a powerful and flexible tool as they enable students to discover things on their own, learn new programming languages, and develop working methodologies and critical thinking.
(Rizki & Suprapto, 2024)	The learning model effectively improves students' critical thinking skills. the learning model exhibits a positive correlation with student achievement, perceived control, and affective perception. This research suggests introducing innovative learning approaches to enhance students' critical thinking skills

(RG 1) Identify Research Trends Regarding Critical Thinking Skills in STEM Integrated Mathematics Learning in the Last 5 Years Publications

The research trends of the last five years are obtained from bibliometric data that has been processed using VOSviewer as shown in Figure 2. The same color indicates the same cluster, and the size of the circle indicates the popularity of the keyword. The larger the size of the circle, the more popular the topic is covered in 10 articles. The connecting line between the circles marks the direct relationship between the keywords.

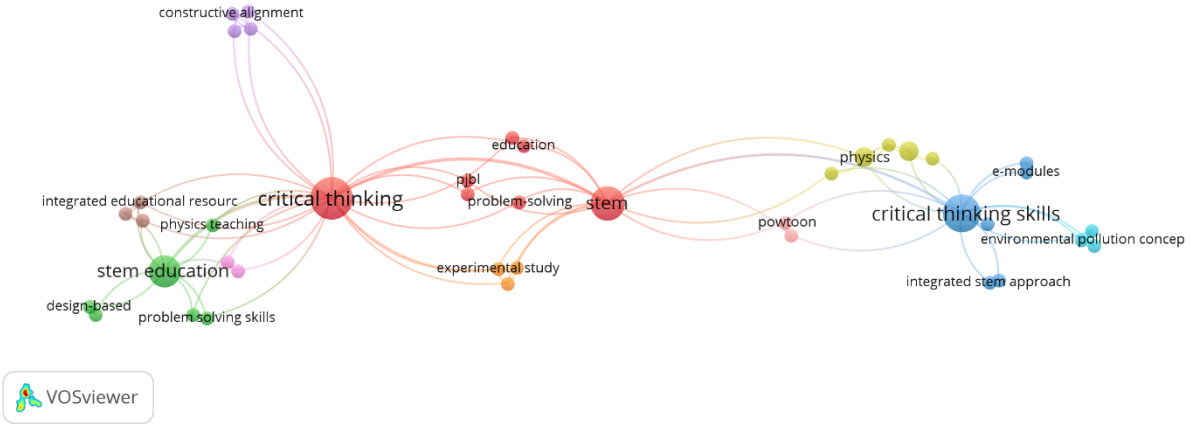

Figure 2. The Keyword Network Visualization of the 20 Processed Articles

Observations of the most frequently researched topics in a certain period of time can reveal research trends on critical thinking in STEM integrated learning in the world of education in the last 5 years. Comparisons were also made to see the trend of critical thinking research from the beginning in education from time to time so that the stages of development could be known. This is reflected in the topics that have emerged in a period and the most popular topics. As shown in Table 4, there are 10 keyword clusters that show the proximity of the keywords in the processed article.

Table 4. Keyword Clusters in Research on Critical Thinking with STEM Integrated Learning

Cluster	Keyword List
1	critical thinking, education, pjbl, post-normal science, problem-solving, self-efficacy, stem
2	design-based, physics teaching, problem solving skills, science critical thinking, scientific creativity, stem education
3	critical thinking skills, e-modules, integrated stem approach, secondary school biology, stem-pbl, stem-pjbl
4	critical thinking ability, elementary school student, physics, problem-based learning, stem approach
5	constructive alignment, professional skills, rubrics, self-regulated learning
6	environmental pollution, mobile, problem based learning, stem based worksheets
7	experimental study, maths teaching, technology acceptance

Cluster	Keyword List
8	integrated educational resource, mobile robotics kits, robotics
9	design based learning, stem perception
10	powtoon, video development

The size of the circle on each keyword indicates the popularity level of the 10 processed research titles. The larger the size of the circle indicates the greater the use of those keywords in the research. This indicates that these variables have previously been extensively researched. The direct relationship between the keyword 'critical thinking' and other keywords is presented in Figure 3.

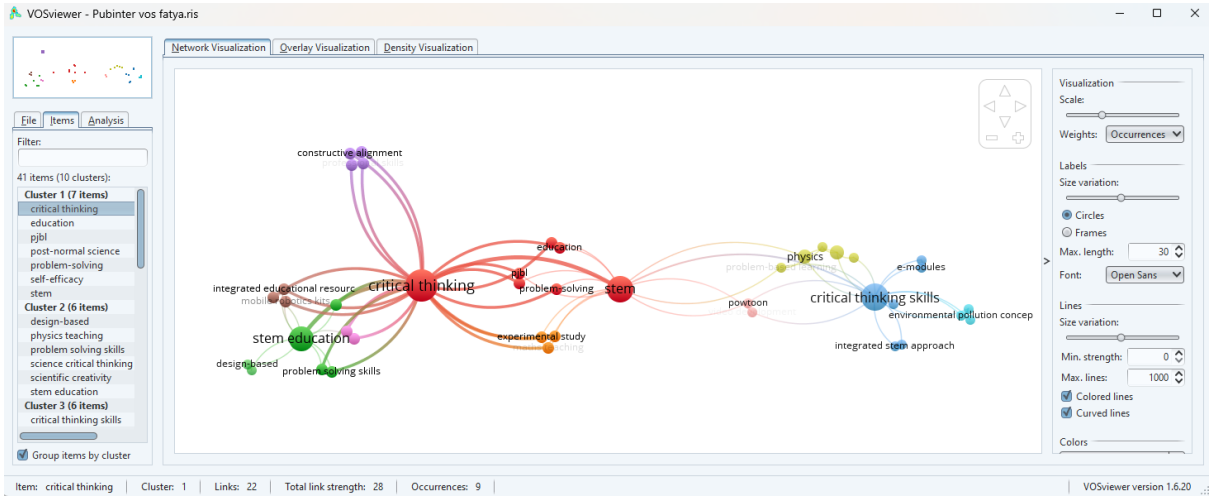

Figure 3. The Relation of 'Critical Thinking' Keyword with Other Keywords

Figure 3 informs that the keyword 'critical thinking' is included in cluster 1 with 22 links and 9 occurrences. The keywords that are closely related to 'critical thinking' are STEM, STEM education, problem solving, problem solving skills, design based, integrated educational, constructive alignment, PJBL, education, and experimental study. These keywords are directly related to other keywords in five different clusters. This can be interpreted that, out of the 10 studies conducted, the keywords in the five clusters are most likely to have been the topic in one research title.

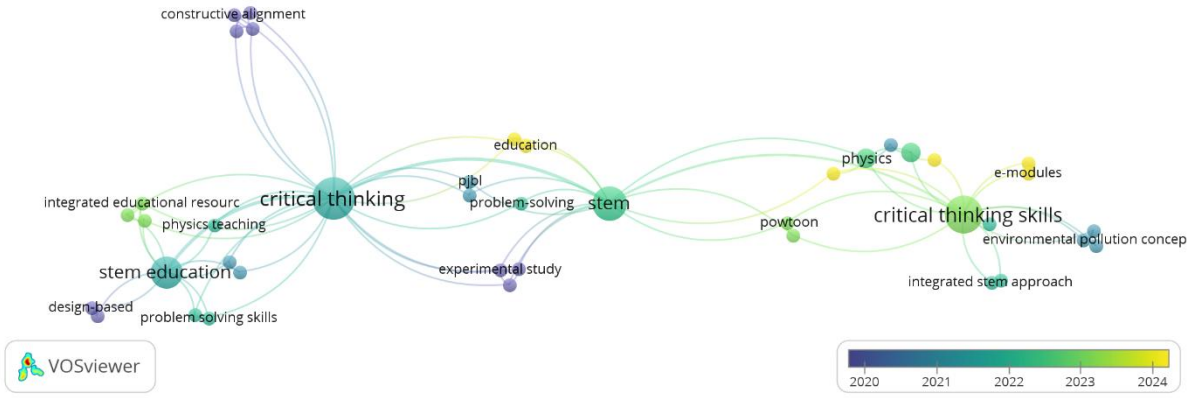

Figure 4. Publication Trend from 2017 to 2020

The trend, as shown in Figure 4, is indicated by color. A brighter sign indicates a newer publication. It can be seen that the most recent trends marked in yellow include the keywords education and e-modules. In addition, it can be seen that the circles that are spread including critical thinking, critical thinking skills, STEM education, and STEM show bright green colors, meaning that the discussion of these keywords is in a study of publications that are still quite new. For researchers, information about the novelty of the topic is important to show the current state of the research conducted in accordance with the times.

(RG 2) The Influence of STEM Integrated Mathematics Learning in Developing Critical Thinking Skills

Research on critical thinking skills in STEM integrated learning from 2020 to 2025 has a research focus to find out if there is an increase in critical thinking skills in learning that integrates STEM in it. Based on the findings of the last 5 years of research, it is concluded that the application of STEM integrated learning in general can encourage and develop students' critical thinking skills (Parno et al., 2021; Rizki & Suprapto, 2024; Mater et al., 2020; Azeem & Rasool, 2024). Studies related to this increase are carried out at various levels of education and in various fields of science, so this shows that STEM integrated learning can be applied from elementary school to university education levels as well as in various studies in the field of science (Parno et al., 2021; Widayanti & Juhji, 2023; .Gencer & Dogan, 2020; Langi, 2024)

The improvement of critical thinking skills in STEM (Science, Technology, Engineering, and Mathematics) integrated learning can be explained from various points of view, ranging from students' attitudes and responses to the classroom atmosphere that is formed. The STEM approach encourages students to think systematically, creatively, and analytically as they are faced with real-world problematic situations that demand collaborative and science-based solutions (Ariefah et al., 2025). When students engage in projects that combine different disciplines, they are naturally driven to evaluate information, compare alternative solutions, as well as test hypotheses through experiments or simulations (Yaki, 2022). This process forms an interactive and participatory classroom atmosphere, where students become not only recipients of information, but also creators of knowledge (Linh et al., 2022). In addition, STEM-integrated learning often uses a project-based approach, which creates an authentic and meaningful learning environment (Rizki & Suprapto, 2024). Students show high enthusiasm and curiosity because they feel that learning activities have direct relevance to their real lives (Topsakal et al., 2022). This creates strong emotional and cognitive engagement, which contributes positively to the formation of critical attitudes. In this atmosphere, teachers act as facilitators who guide students' thought processes without dictating too much, providing space for the exploration of ideas and open discussions. As a result, students become more independent in thinking, open to other points of view, and trained to formulate and test arguments logically (Guerra, 2024).

Various studies have been conducted to measure critical thinking skills in the context of STEM learning, using a variety of indicators developed by experts. For example, research by Gencer & Dogan (2020) measure the critical thinking skills of fifth graders through a STEM-based design approach, using indicators from Ennis that include the skills of explaining, summarizing and evaluating arguments. The results show that students experience improvements in identifying problems and formulating logic-based solutions. Meanwhile, Parno et al (2021) using

a STEM approach to static fluid materials and adopting indicators from Facione, namely interpretation, analysis, evaluation, inference, and explanation. This study revealed that the analysis and inference indicators experienced the most significant increase because students were used to comparing experimental data. Another case is with research Yaki (2022) who observe high school students on biology material. Yaki uses indicators from Paul and Elder, such as clarifying problems, examining assumptions, and making evidence-based decisions. This research shows that the STEM approach allows students to craft stronger data-driven arguments. On the other hand, Linh et al (2022) from Vietnam emphasizes the orientation of STEM programs towards the development of critical thinking by incorporating indicators from *Bloom's Revised Taxonomy*, such as analyzing, evaluating, and creating, all of which show an increasing trend in post-test outcomes. Reynders et al (2020) develop a specific rubric to measure critical thinking in college-level STEM education, combining aspects of information analysis and reflection. All of these studies underscore that the critical thinking indicators used vary depending on the context, but all highlight the tangible benefits of the STEM approach in developing these abilities.

The development of STEM integrated learning designs continues to evolve with a variety of innovative approaches that are proven to improve students' critical thinking skills. Hacioglu & Gulhan (2021) demonstrate that STEM integration involving experiments and problem-based projects is able to encourage students to evaluate and interpret information in depth. Meanwhile, Asigigan & Samur (2021) blending elements of gamification in STEM practice, which not only enhances students' intrinsic motivation but also their critical thinking disposition. A fun and challenging approach like this fosters students' ability to make logical decisions and consider a variety of alternative solutions. In addition, integrated STEM practices can be oriented towards problem solving, where students are given an active role to design solutions to real problems, encourage scientific creativity and precision in thinking (Hebebci & Usta, 2022). In the local context, the application of the PjBL-STEM approach to ecosystem and recorded materials can improve critical thinking as well as self-efficacy, as they engage in challenging and collaborative projects (Allanta & Puspita, 2021). Hasanah et al (2021) dan Langi (2025) It was also found that the integration of the Problem Based Learning (PBL) model with the STEM approach was able to improve critical thinking indicators such as interpretation and evaluation because students were used to studying complex problems and finding solutions through scientific exploration. There has also been the development of PowToon's animation-based learning media within the STEM framework, and the results show an increase in students' cognitive engagement in analyzing information (Widayanti & Juhji, 2023). Other research also applies the use of mobile robotics in STEM approaches encouraging students to think systemic and interdisciplinary (Antunes et al., 2023). Thus, the development of STEM-integrated learning designs, whether project-based, problem-based, interactive media, and robotics, has been proven to be able to enrich students' critical thinking processes because they are required to be active, collaborative, and reflective in their learning process.

Conclusion

Based on the results of a systematic review of 20 studies over the past five years, it can be concluded that STEM integrated learning consistently makes a positive contribution to improving students' critical thinking skills. This approach is effectively applied at various levels of education and science, by utilizing methods such as problem-based projects, gamification, and interactive media. STEM encourages students to think systematically,

reflectively, and collaboratively in dealing with real-world problems, as well as training them in evaluating, analyzing, and crafting evidence-based arguments.

The study has a limitation on the number of articles analyzed, namely only ten publications in the 2020–2025 time frame, which can limit the scope of generalization of the findings. In addition, the variation in critical thinking indicators used in each study made the comparison of results less homogeneous. Another limitation is that not all local approaches or contexts are represented in the analysis, so a broader and more in-depth follow-up study is needed to corroborate these systematic findings. In addition, judging from research trends, it is recommended to delve deeper into the topic in methods other than quantitative. In addition, in collecting data on literature reviews, databases other than Google Scholar, Crossref, and Scopus can be used.

Recommendations

Based on the results of the study, STEM integrated learning has been proven to have the potential to improve students' critical thinking skills. Therefore, teachers are advised to integrate models such as PjBL or PBL in the STEM approach. Teacher training on critical thinking design and assessment also needs to be improved. Schools should support implementation by providing adequate learning resources and practice facilities. In addition, further research is recommended to reach more diverse contexts so that STEM implementation can be more inclusive and relevant in various educational settings.

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