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The Impact of STEM Education on Students' Critical Thinking Skills: A Systematic Literature Review

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Abstract: This systematic literature review examines the impact of STEM (Science, Technology, Engineering, and Mathematics) education on developing students' critical thinking skills. This review synthesizes studies from the last decade to assess how various STEM-based learning approaches can improve students' critical thinking skills at multiple levels of education. By analyzing various empirical studies, this review explores the effectiveness of STEM activities based on project-based learning, hands-on experiments, and interdisciplinary approaches in promoting higher-order thinking skills, problem-solving abilities, and decision-making processes. This study aims to identify challenges and obstacles in the implementation of STEM education, such as a lack of teacher training, limited resources, and the need for curriculum alignment. We searched for publications from 2015 to 2025 in four bibliographic databases: Scopus, Eric, EBSCO, and ScienceDirect. We identified 96 articles, of which 23 met the critical thinking criteria and were systematically analyzed. These findings prove that STEM education positively impacts students' critical thinking skills. Key factors such as discovery-based learning, problem-solving tasks, interdisciplinary teaching approaches, and collaborative learning were identified as significant contributors to the development of critical thinking. The research findings indicate that STEM education has great potential to enhance critical thinking skills among students, particularly when employing practical, collaborative, and discovery-based approaches. However, further high-quality, long-term studies are needed to confirm these effects and discourse methodological limitations in the current research.

Keywords: STEM education, Critical thinking skills, STEM teaching methods, Systematic literature review

Introduction

Global development requires transformation in various domains, including competencies; thus, 21st-century students are directed to achieve proficiency in these competencies (Sumantri, 2019; Warsita, 2017). Initiatives assumed by government agencies and educators in this century aim to nurture students who can be relied upon for the future by building a more innovative educational framework and enhancing 4C skills, which include critical thinking, effective communication, creative thinking, and collaborative work.

Computational thinking skills have been integrated into the 5C framework, evolving from the previously established 4C framework, as these skills are crucial for enhancing students' ability to tackle complex problems (Azmi & Ummah, 2021; Nuvitalia et al., 2022; Sa'diyyah, 2021). Educational advancements in the 21st century mandate the integration of creative, critical, and computational thinking skills. The current state of thinking skills in Indonesia is severely lacking; this can be attributed to the fact that these skills require a high level of reasoning not only during assessment but must also be effectively applied throughout the educational process (Fithri et al., 2021; Hasanah et al., 2021). Students tend to face challenges in developing critical thinking competencies if the educational process fails to implement methods and models that encourage the development of critical thinking (Basthomi et al., 2021). The deficiencies observed in creative thinking skills can be traced back to instructional processes that do not encourage students to engage their imagination, thereby hindering the application of learning in real-world contexts (Ermaita, 2016; Sutama et al., 2014). Inadequate computational thinking skills arise from pedagogical approaches and models that limit students' opportunities to independently develop their problem-solving abilities in a structured manner (Angraini et al., 2022; Supiarmo et al., 2022).

STEM (Science, Technology, Engineering, and Mathematics) constitutes an integrative educational framework encompassing the fields of science, technology, engineering, and mathematics. The significance of these disciplines has escalated in contemporary society, as they are integral to the cultivation of competencies required to fulfil the demands of both the corporate sector and the broader community (Seage et al., 2020). The incorporation of STEM pedagogy during the early childhood phase facilitates the enhancement of foundational cognitive, emotional, and social competencies in young learners. This developmental epoch is pivotal, characterized by the rapid acquisition of knowledge and the formation of fundamental habits and interests (Smeddy, 2023). Consequently, the strategic implementation of STEM education during this critical phase has the potential to establish a robust groundwork for the future achievements of children.

Previous studies have shown that the implementation of STEM education can have a positive impact on students' critical thinking skills at various levels of education (Margot & Kettler, 2019; Becker & Park, 2011). However, despite various findings supporting the effectiveness of STEM education, existing research results still show significant variations in terms of context, methods, and measured outcomes. Therefore, it is important to conduct a systematic review to identify and synthesize empirical evidence regarding the impact of STEM education on students' critical thinking skills.

Critical thinking is a cognitive effort that includes the capacity to interrogate, analyze, synthesize, and evaluate information (Facione, 2011). This cognitive effort enables individuals to develop a critical disposition toward information while assessing their reasoning with logical rigor. Individuals engaged in critical thinking approach information not only at a superficial level, but rather with deep and analytical scrutiny. Furthermore, critical thinking is intrinsically linked to the capacity to understand and articulate diverse perspectives with clarity (Ennis, 1991). The preschool stage is an important developmental phase during which children acquire fundamental cognitive and emotional competencies. Nurturing critical thinking skills during this formative period can facilitate the emergence of a disposition to be curious about information and enhance their problem-solving capacity (Göktürk, 2015). The development of critical thinking skills in early childhood education can significantly influence children's subsequent academic achievement and their proficiency in tackling complex problems.

Therefore, there is an urgent need to conduct a comprehensive and methodological systematic literature review to critically integrate and evaluate existing empirical evidence. This review aims to answer the main question: *To what extent does STEM education contribute to improving students' critical thinking skills?* Through a systematic approach, this study is expected to identify trends, research gaps, and factors that influence the effectiveness of STEM education in the context of critical thinking development. Thus, the results of this study will not only enrich academic discourse but also provide a strong foundation for more targeted and evidence-based educational policy-making, curriculum development, and teacher training.

Method

A comprehensive systematic literature review has been undertaken to discern and scrutinize the pertinent research pertaining to risk management within the domain of innovation development projects conducted over recent years. The primary advantages of this methodological approach encompass the capacity to extract relevant information from an expanding corpus of publications that may exhibit similarities or contradictions. The employment of a compilation of scholarly articles furnishes a holistic perspective of literature, in contrast to the examination of a circumscribed body of literature. Consequently, the resultant findings and analyses

generated are dissociated from the particularities of any single case study. Systematic reviews must adhere to principles of transparency and rigor to guarantee the integrity of the findings and analyses presented. In executing this review, the PRISMA protocol was employed (Moher et al., 2015), which is particularly aligned with the objectives of our study. This protocol encompasses four distinct phases essential for conducting a systematic literature review: identification, screening, eligibility, and the inclusion of a selected set of articles (Figure 1).

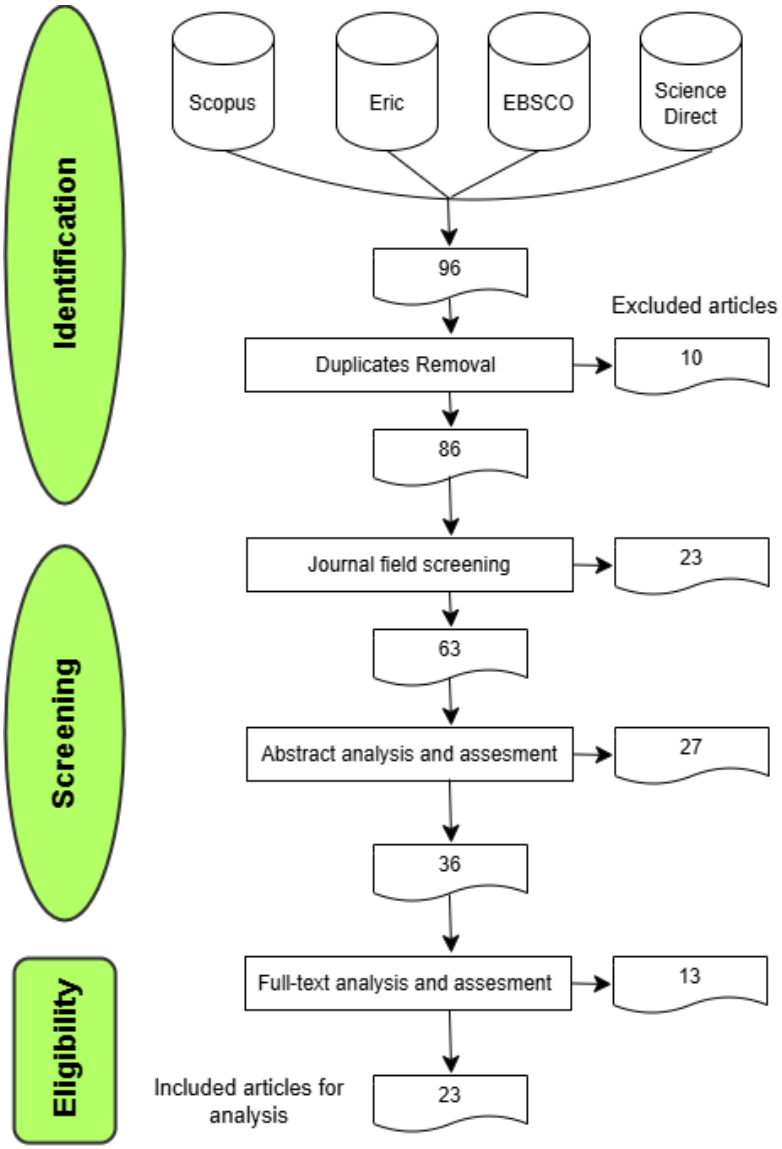

Figure 1. Flow diagram of the systematic literature review based on the PRISMA framework.

Identification

A set of keywords has been established based on the research questions and refers to two fields of literature related to STEM Education and Critical Thinking, particularly in the field of education. A set of keywords has been established based on the research questions and refers to two fields of literature related to STEM Education and Critical Thinking, especially in the field of education. The keywords include a combination of TITLE-ABS-KEY (stem AND education AND critical AND thinking).

The selection of these keywords aims to explore the relationship between STEM Education and critical thinking in the broader field of education. STEM Education research has undergone significant development in recent years. To conduct a literature review, four main databases were consulted: Science Direct, Eric, EBSCO, and Scopus. Keywords were searched based on “Title” and “Field” through the database search engine. This

systematic review covers the period between 2015 and 2025. Only articles written in English were considered. This step resulted in the identification of 96 articles. After removing duplicates, 23 publications were collected.

Screening

The screening process consisted of two stages, namely journal field screening and abstract analysis. First, 86 articles identified in the previous stage were screened based on the journal's research field. 23 articles were excluded because they were published in journals outside the field of education research. For example, the excluded articles were in the fields of language, engineering, arts, and health. 63 articles were retained for further analysis in the abstract analysis stage.

For abstract analysis, two criteria were established: i) application of STEM education (e.g., science education, mathematics, etc.); and ii) contribution to the scope of research in the field of education in general. Two researchers conducted the reading and placement of abstracts in parallel and independently based on the two inclusion criteria. Only articles that met both criteria for both researchers were included for further analysis. If there were differences between the researchers' results, discussions were held until consensus was reached. A total of 27 articles were rejected. For example, rejected articles did not discuss critical thinking or STEM education. Some rejected articles did not discuss the relationship between STEM education and critical thinking. A total of 36 articles were selected for full-text analysis.

Eligibility

The thirty-six articles selected for this study were examined comprehensively. A rigorous analysis was performed from two distinct vantage points, specifically descriptive and thematic. The descriptive dimensions that informed the reading process encompassed: temporal scope (2015–2025), domain of inquiry (education), research methodology (theoretical or empirical), and the nature of contributions made by the reviewed articles (e.g., mathematical models, theoretical frameworks, typologies, etc.). Only those articles that evidenced contributions relevant to the research questions were incorporated for both descriptive and thematic analysis, as elucidated in the subsequent sections. Ultimately, a total of twenty-three articles were integrated into this literature review to enhance the understanding of the relationship between STEM education and critical thinking within this interdisciplinary research domain.

Results and Discussion

Temporal Distribution

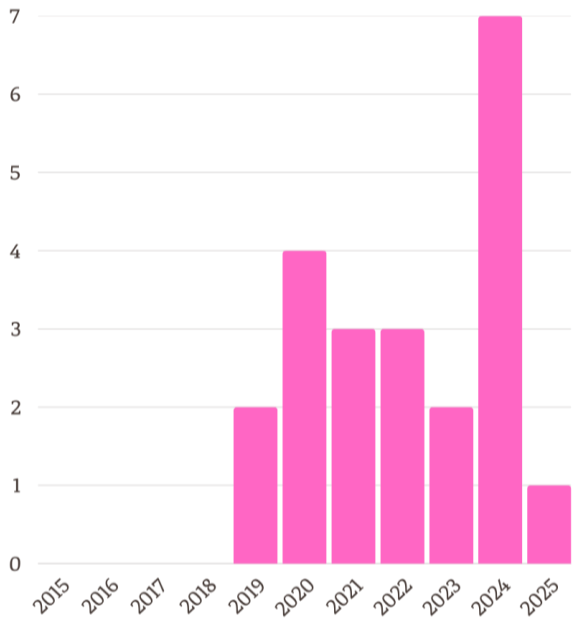

Figure 2. Distribution of articles per year.

Figure 2 shows the distribution of articles over time, indicating an increase in interest in the study of the influence of STEM education on students' critical thinking skills over time. An important study by several researchers was identified, in which STEM education and its influence on students' critical thinking skills were examined from various perspectives, including project-based and problem-based learning approaches. Although literature on STEM education and critical thinking skills existed prior to the 2025s, a significant number of studies began to appear after 2015, with a total of 23 articles in our database, covering 80% of the literature we reviewed. This literature reveals that STEM education is now one of the main drivers in the development of students' critical thinking skills at various levels of education. For example, the shift in learning approaches from traditional to project-based and problem-solving learning (Gao et al., 2012; Roper and Tapinos, 2016), as well as the use of technology in STEM education reinforce the role of STEM in enhancing students' critical thinking skills (Euchner, 2013; Brunswicker & Chesbrough, 2018).

Knowledge Fields

In the 23 articles consulted, there were a number of conferences and book chapters related to the influence of STEM education on students' critical thinking skills. The journal articles were published in 13 different journals, the most relevant of which are listed in Table 1. For further analysis, these journals were classified according to field of knowledge. Journal articles were classified according to Scopus categories. For conference papers and book chapters, the knowledge categories were determined based on the main theme of the conference and book, following the Scopus categories as for the journals. As shown in Figure 3, 51% of the journals were in the field of education and psychology, while 41% were from non-education fields. Conversely, a small proportion of studies relate to the fields of social sciences and humanities (4%); health sciences (2%); and economics (2%). It can be seen that the number of publications originating from the fields of education, psychology, and engineering is fairly balanced, indicating the importance of these topics from both perspectives.

Some articles adopt a stronger perspective from one field than another. Articles related to education and psychology focus on how STEM education can improve students' critical thinking skills through project-based learning and problem-solving approaches. For example, research by Brown and Osborne (2013) argues that STEM education provides opportunities to develop students' analytical and creative abilities through active and collaborative learning. On the other hand, articles from the fields of engineering and computer science place more emphasis on the use of STEM technologies and tools in supporting the development of students' critical thinking skills. For example, Chen (2018) argues that the application of technology in STEM learning allows students to be more involved in experiments and simulations that enhance their understanding of complex problem solving. In addition, Keizer and Halman (2007) propose innovative methods of using technological tools to support STEM learning that focuses on developing students' critical thinking skills.In contrast to this focused view, many authors argue that a multidisciplinary approach that combines both perspectives, education and technology, is necessary to develop more holistic critical thinking skills in students (Hoecht and Trott, 2006; Ning & Ruoyu, 2007; Wang et al., 2010). For example, for Hoecht and Trott (2006), innovation in STEM education involves not only technical aspects but also changes in teaching and learning processes that influence students' behavior and attitudes toward learning challenges.

Literature's Approaches and Contributions

The literature reviewed in this study was analyzed based on the research methodology used, which was classified into empirical and theoretical research. In addition, the analysis was conducted based on the type of contribution made, which was categorized into concept development and method proposals (Kothari, 2004). Regarding research methodology, several subcategories were identified. Empirical research is classified into case studies, surveys, and experimental research designs. Meanwhile, theoretical research is divided into literature analysis and mathematical theory development. As shown in Figure 4, most studies (73%) fall into the empirical research category.

This approach is highly beneficial for building theory and verifying existing theories, and is widely applied in emerging fields of study, including the impact of STEM education on students' critical thinking skills. This indicates that research on the impact of STEM education is still in its exploratory phase. The distribution between case studies, surveys, and experimental research designs is fairly balanced. The remaining 27% of the analyzed publications adopted theoretical research. In this category, literature analysis is more dominant than mathematical theory formation, indicating that the existing literature focuses more on theoretical studies than on the development of mathematical models.

Table 1. Articles distribution among the most representative journals.

Journal	#	%
Journal of College Science Teaching	1	4,3%
Biochemistry and Molecular Biology Education	1	4,3%
Research and Development in Education	1	4,3%
Anadolu University Journal of Education Faculty	1	4,3%
Remittances Review	1	4,3%
Geojournal of Tourism and Geosites	1	4,3%
Indonesian Review of Physics	1	4,3%
Education Sciences	2	8,6%
Specialusis Ugdymas	1	4,3%
Early Child Development and Care	1	4,3%
Jurnal Pendidikan IPA Indonesia	1	4,3%
Journal of Science Education and Technology	1	4,3%
International Journal of STEM Education	1	4,3%
Journal for the Education of Gifted Young Scientists	2	8,6%
AL-TA'LIM JOURNAL	1	4,3%
Revista de Gestão Social e Ambiental	1	4,3%
International Journal of Assessment Tools in Education	1	4,3%
International Journal of Education in Mathematics, Science and Technology	1	4,3%
Science Education International	1	4,3%
Jurnal Tarbiyatuna	1	4,3%
International Online Journal of Education and Teaching	1	4,3%

Table 2. List of the most cited articles

Article title	# citations	Authors	Knowledge
Overcoming Obstacles and Finding Support for Teaching Critical Thinking in STEM	120	(Evangelisto, 2023)	STEM Education
Developing critical thinking in STEM education through inquiry-based writing in the laboratory classroom	143	(Jeon et al., 2021)	STEM Education
Harnessing Project-Based Learning to Enhance STEM Students' Critical Thinking Skills Using Water Treatment Activity	172	(Oyewo et al., 2022)	STEM Education
Inquiry vs. Inquiry-Creative: Emphasizing Critical Thinking Skills of Prospective STEM Teachers in the Context of STEM Learning in Indonesia	130	(Prayogi et al., 2024)	STEM Education
Integrating a hybrid mode into kindergarten STEM education: Its impact on young children's critical thinking skills during the COVID-19 pandemic	356	(Zhang et al., 2024)	STEM Education

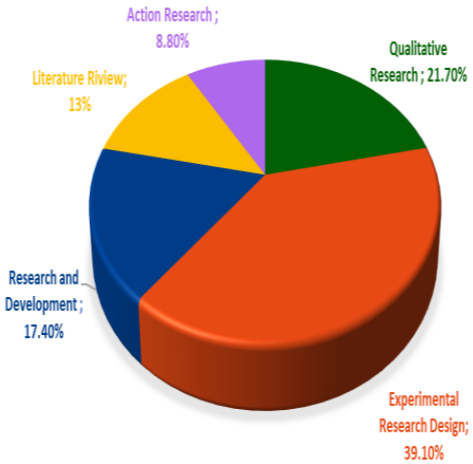

Figure 3. Number of articles according to the methodological approach.

This article analyzes various research methodologies, as shown in the pie chart. The distribution shows the approaches used in this field, with Action Research (8.7%) reflecting its significant role in practical and participatory educational studies. Research with an Experimental Research Design accounts for 39.1%, emphasizing a focus on structured and controlled studies to understand specific variables. Qualitative Research contributes 21.7%, highlighting the importance of non-numerical data and a deep understanding of phenomena. Research and Development (R&D) contributed 17.4%, indicating studies dedicated to the creation and testing of new methods or technologies. Finally, Literature Reviews contributed 13%, highlighting the importance of continuously synthesizing existing research to build a foundation for future studies. These findings show that most research in this field focuses on practical and applied methods (Experimental Research Design), with less emphasis on theoretical contributions (Literature Review).

Table 3. The impact of STEM education

No	Authors	Area	Factor	Improvement	Years
1	(Jeon et al., 2021)	Education	Inquiry-based learning encourages students to ask questions, seek answers, and think critically about the results they find.	Increased student engagement after STEM learning in the laboratory	2020
2	(Indranuddin et al., 2024)	Education	STEM-PjBL encourages students to think outside the box when designing solutions to given problems.	Students can identify problems and evaluate various potential solutions.	2024
3	(Uyulan & Aslan, 2024)	Education	STEM activities carried out in early science education encourage students to think more deeply and analytically.	Students become more familiar with critical thinking processes in facing challenges.	2024
4	(P, 2022)	Education	STEM encourages students to work on real-world problems that require critical analysis, experimentation, and problem solving.	Students are more engaged and motivated to solve problems.	2024
5	(AlAli, 2024)	Education	STEM learning enables students to use digital tools in experimentation, data analysis, and solution design.	Students are better trained in analyzing problems in depth, developing creative solutions, and making decisions based on evidence.	2024
6	(Winarti et al., 2021)	Education	Teachers who act as facilitators in STEM learning help students organize their thinking.	STEM-based physics learning significantly improves students' analytical skills.	2021
7	(Oyewo et al., 2022)	Education	Practical experiments in water treatment give students the opportunity to be directly involved in data collection and experimentation.	Students are trained to identify and solve real problems related to water treatment.	2022
8	(Arsilawita et al., 2022)	Education	STEM-based learning encourages students to think analytically when facing problems.	Students to be more actively involved in learning, which improves their critical thinking skills through direct experience in problem solving.	2022
9	(Prayogi et al., 2024)	Education	The inquiry approach focuses on open-ended investigation, in which students ask questions and seek answers through experimentation or research.	The Inquiry and Inquiry-Creative approaches encourage students to analyze, evaluate, and make decisions based on evidence.	2024
10	(Zhang et al.,	Education	STEM activities designed to	The integration of STEM	2024

	2024)		spark children's interest and encourage them to think critically.	learning with a hybrid mode (a combination of online and face-to-face learning) provides students with the opportunity to participate more actively in STEM-based experiments and activities.	
11	(Evangelisto, 2023)	Education	Many STEM educators face resource constraints, such as limited access to the technology devices needed for STEM-based experimentation and learning.	STEM teachers receive more specialized training on teaching critical thinking and instructional strategies that support the development of critical thinking skills.	2023
12	(Iqbal Ainur Rizki, 2024)	Education	Project-based PBL gives students the opportunity to work on real-world problems.	Students are involved in real-world projects related to renewable energy, which require them to analyze problems, explore solutions, and solve problems creatively.	2024
13	(Reynders et al., 2020)	Education	This section not only assesses traditional academic abilities, but also 21st-century skills.	By using clear and structured rubrics, students become more aware of how to think critically in the context of STEM problems.	2020
14	(Priatna et al., 2020)	Education	Project-based learning approaches, technology integration, collaboration, and the role of teachers as facilitators play a major role in supporting the development of critical thinking skills in the context of STEM.	STEM-based learning encourages students to think more deeply about mathematical concepts, connect theory with real-world applications, and analyze problems using logical approaches.	2020
15	(Aswirna et al., 2022)	Education	The integration of local wisdom, the use of technology, project-based learning, and the role of teachers as facilitators play a major role in supporting the improvement of critical and creative thinking skills.	By using STEM-based e-modules that integrate local wisdom about the use of rice stalks as fertilizer, students are presented with questions and problems that require in-depth analysis.	2022
16	(Astawan et al., 2023)	Education	STEM-based learning integrates science, technology, engineering, and mathematics, enabling students to see the connections between disciplines.	STEM-based learning encourages students to think more critically in identifying problems, evaluating various solutions, and developing systematic problem solving.	2023
17	(Savran et al., 2020)	Education	A design-based approach, collaboration, the role of teachers, and technology play key roles in supporting the development of students' critical thinking skills.	Through design-based STEM education, students are confronted with real-world problems that require them to think critically, analyze data, and make decisions based	2020

				on scientific evidence.	
18	(Asigigan & Samur, 2021)	Education	Gamification in STEM learning often involves the use of digital platforms and interactive software, which allow students to access content in a more dynamic way and receive immediate feedback.	STEM learning increases students' intrinsic motivation because they feel more engaged and challenged by the challenges presented in the form of games.	2021
19	(Topsakal et al., 2022)	Education	The role of teachers as facilitators is a factor that greatly influences the success of improving students' critical thinking and problem-solving skills.	Problem-based STEM education has a significant positive impact on students' critical thinking tendencies and perceptions of problem-solving skills.	2022
20	(Wahyuningtyas & Widiyono, 2024)	Education	Discovery-based approaches, the use of technology, the role of teachers as facilitators, and parental involvement play an important role in strengthening students' understanding of the material.	The application of STEM-based Discovery Learning in fraction learning in Islamic education can significantly improve students' critical and creative thinking skills.	2024
21	(Isdianti et al., 2021)	Education	The inquiry approach, STEM integration, use of technology, the role of teachers as facilitators, and constructive formative assessment play a major role in supporting the development of critical thinking in students.	The use of inquiry-based learning in STEM packages provides students with opportunities to think analytically, analyze data, and make evidence-based decisions.	2021
22	(Retnowati et al., 2020)	Education	Project-based learning approaches in STEM give students the opportunity to work on real-world problems, encouraging them to think more critically in evaluating and selecting appropriate solutions.	The implementation of rectangular STEM-based modules is highly effective in improving students' critical thinking and problem-solving skills.	2020
23	(Widyawati et al., 2024)	Education	Project-based approaches, the use of technology, the role of teachers as facilitators, and collaboration among students play a major role in strengthening critical thinking and scientific communication skills in an Islamic values-based STEM context.	The integration of Tamansiswa teachings (Niteni, Nirokke, Nambah) with E-PBL-STEM is highly effective in improving students' critical thinking skills and scientific verbal representation.	2024

Conclusion

This systematic literature review emphasizes the significant impact of STEM (Science, Technology, Engineering, and Mathematics) education on the enhancement of students' critical thinking abilities. Many studies indicate that integrating STEM curricula helps improve students' skills in analysing, assessing, and solving complicated problems, all of which are fundamental to critical thinking. The hands-on, inquiry-driven nature of STEM education encourages students to ask questions, engage in investigations, and make evidence-

based decisions. The findings consistently show that STEM education look after higher-order thinking by urging students to approach problems with creativity and critical insight, especially in real-world scenarios. This not only improvements their academic performance but also prepares them with the skills needed for careers that request problem-solving and analytical thinking. Nevertheless, the review also highlights certain research gaps, especially regarding the lack of longitudinal studies that assess critical thinking skills over time. More research is needed to investigate the long-term effects of STEM education on critical thinking and how specific teaching methods within STEM may influence these abilities. In conclusion, the evidence strongly affirms that STEM education plays a crucial role in developing critical thinking skills. However, further research is needed to gain a deeper understanding of how particular components of STEM education contribute to the growth of these vital skills.

Recommendations

Based on the insights gained from the systematic literature review on the effect of STEM education on students' critical thinking, the following suggestions are proposed: 1) Strengthen the Integration of STEM Subjects: Schools and universities should further integrate STEM fields into their curricula by developing interdisciplinary courses that combine science, technology, engineering, and mathematics. 2) Prioritize Inquiry-Based Learning: Educational institutions should place a greater emphasis on inquiry-based and experiential learning methods within STEM disciplines. 3) Conduct Long-Term Research on Critical Thinking: Future studies should focus on long-term research to track the development of critical thinking skills over time in students involved in STEM education. 4) Customize Teaching Methods to Boost Critical Thinking: Teachers should explore and implement a variety of teaching techniques within STEM courses that specifically target the enhancement of critical thinking. 5) Expand STEM Learning Beyond the Classroom: Schools should encourage informal STEM education through activities such as after-school clubs, science fairs, and extracurricular programs.

Scientific Ethics Declaration

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

Conflict of Interest

* The authors declare that they have no conflicts of interest

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