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SYSTEMATIC LITERATURE REVIEW: THE IMPACT OF THE STEAM LEARNING APPROACH ON CRITICAL THINKING SKILLS IN SCIENCE EDUCATION

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Abstract
This study aims to systematically examine empirical evidence from the past five years regarding the impact of the Science, Technology, Engineering, Art, and Mathematics (STEAM) approach on students' critical thinking skills at the primary and secondary education levels. A qualitative Systematic Literature Review (SLR) method was employed. The literature was collected via Google Scholar, focusing on publications from 2019 to 2024, using a combination of keywords in both Indonesian and English. Out of 98 articles initially identified, only ten were selected based on inclusion and exclusion criteria, and further assessed using the Joanna Briggs Institute Checklist for quality appraisal. Data were analyzed using thematic analysis, categorizing studies based on educational level, subject matter, learning models, research methods, instruments used, and research outcomes. The review findings indicate that approximately 90% of the studies reported a significant improvement in students' critical thinking skills through the implementation of Project-Based Learning (PjBL) integrated with STEAM. The most substantial effects were observed at the senior high school level, particularly in Physics and Biology subjects. At the elementary level, the STEAM approach was more effective when combined with play-based or exploratory learning activities. In junior high schools (SMP and MTs), STEAM served as a bridge between foundational conceptual understanding and the development of analytical skills. These findings highlight that the effectiveness of STEAM is highly contextual and influenced by students' cognitive readiness, teacher support, and the socio-economic conditions of schools. The study concludes that STEAM should not be viewed merely as a pedagogical strategy, but as an adaptive educational practice. Practical implications include the need for differentiated instructional strategies, equitable access to learning resources, and teacher training programs to support more widespread and equitable implementation.
Kata kunci: STEAM education; Critical thinking; Science learning; Systematic literature review

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INTRODUCTION

In 21st-century education, critical thinking is recognized as one of the fundamental competencies that must be cultivated, particularly in the context of science learning (Mantau & Talango, 2023; Mardhiyah et al., 2021; Nabilah, 2020). In an era defined by globalization and rapid technological advancement, the ability to analyze problems and design innovative solutions has become an indispensable skill (Hartati et al., 2023; Herman et al., 2024; Patras, 2023). In practice, the teacher's role is no longer limited to delivering content but extends to being a facilitator who fosters a classroom environment conducive to developing critical thinking skills (Komalasari et al., 2020; Nuraida, 2019). These skills enable students to examine issues from multiple perspectives, understand complexity, and develop creative and applicable solutions (Adilla & Ratnawulan, 2023; Indriyana & Susilowati, 2020; Uslima et al., 2023). Despite their acknowledged importance, the effective implementation of instructional strategies that foster critical thinking remains a significant challenge in schools.

Conceptually, critical thinking encompasses the ability to systematically and logically analyze, evaluate, and interpret information (Setiana, 2018; Sohilait et al., 2023). It allows students to make informed decisions based on evidence while considering diverse perspectives (Fitriani et al., 2019; Nantara, 2021). In science education, critical thinking is vital as it helps learners formulate probing questions, recognize patterns, and assess the reliability of information (Basri et al., 2021; Qodarsih et al., 2023). Students with strong critical thinking skills are generally more proactive in identifying problems, constructing rational arguments, and validating information through empirical evidence (Mayla et al., 2024; Setiana, 2018). Unfortunately, empirical data in the Indonesian context suggest that students' critical thinking skills remain relatively low.

Several studies corroborate this finding. A preliminary study by Mislah et al. (2024) revealed that students' critical thinking scores on the topic of global warming averaged only 38.4 out of 100. Similar results were reported by Putri et al. (2023), with high school students scoring an average of 55.73 out of 100. Meanwhile, Sugandi & Siswanto (2021) found that students' critical thinking skills on the topic of simple machines were categorized as moderate, with an average score of 17.3 out of 40. These findings highlight a significant gap in students' mastery of critical thinking, especially when confronting science topics that require deeper analysis. This situation underscores the need for more contextual and interactive learning approaches that bridge the gap between 21st-century skill demands and current classroom practices.

One promising approach is STEAM (Science, Technology, Engineering, Art, and Mathematics). This instructional model emphasizes interdisciplinary integration and real-world problem-solving, which can foster critical thinking, creativity, and collaboration (Tiasna et al., 2023). A growing body of research supports this perspective. Fitriyah & Ramadani (2021) demonstrated that project-based learning (PjBL) with a STEAM orientation significantly enhanced creativity and critical thinking in biology education. Similarly, Aulia et al. (2022) found that STEAM-based physics instructional materials were effective in improving scientific creativity and critical thinking on the topic of heat and temperature. Muntamah et al. (2024) also emphasized the strategic potential of the STEAM approach in preparing young generations to face global challenges. Nevertheless, the effectiveness of STEAM varies due to contextual factors, teacher readiness, and limited supporting resources (Khoiriyyah et al., 2022; Liah et al., 2024), revealing the need for more comprehensive exploration.

Although existing literature affirms that STEAM-based instruction can improve critical thinking skills, the findings are often partial—limited to specific educational levels or topics—and lack a holistic view across diverse educational contexts. This limitation creates a gap in understanding the broader effectiveness of STEAM in science education. In fact, 21st-century education demands more comprehensive, evidence-based strategies to address the complexity of global challenges. Therefore, a systematic review is needed to consolidate recent empirical findings and present a comprehensive synthesis of STEAM's effectiveness in developing students' critical thinking skills across various educational levels.

Grounded in this rationale, the present study aims to systematically examine empirical evidence from the past five years regarding the influence of the STEAM approach on students' critical thinking skills in primary and secondary education. Theoretically, this study is expected to enrich science education literature by highlighting the role of interdisciplinary learning in fostering critical thinking.

Practically, the findings may serve as a foundation for teachers, researchers, and policymakers in designing STEAM-based instructional strategies that are more applicable, contextual, and aligned with 21st-century learning demands.

METHOD

This study employed a Systematic Literature Review (SLR) method with a qualitative approach to examine articles discussing the impact of STEAM-based instruction on students' critical thinking skills in the context of science education. The literature search was conducted through Google Scholar, focusing on publications from 2019 to 2024, using a combination of keywords: “pembelajaran STEAM” AND “berpikir kritis” AND “pembelajaran IPA”, as well as “STEAM learning” AND “critical thinking” AND “science education”. Boolean operators and year filters were applied to refine the search. The initial identification process yielded 98 articles.

The article selection process was carried out purposively using the following inclusion criteria: (1) empirical studies that had undergone peer-review, (2) indexed in at least Sinta 5, (3) relevant to the topic of STEAM and critical thinking, (4) available in full-text format, and (5) published between 2019 and 2024. Articles were excluded if they were: non-empirical, duplicates, irrelevant to the research topic, or inaccessible in full-text. The selection process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram, as shown in Figure 1.

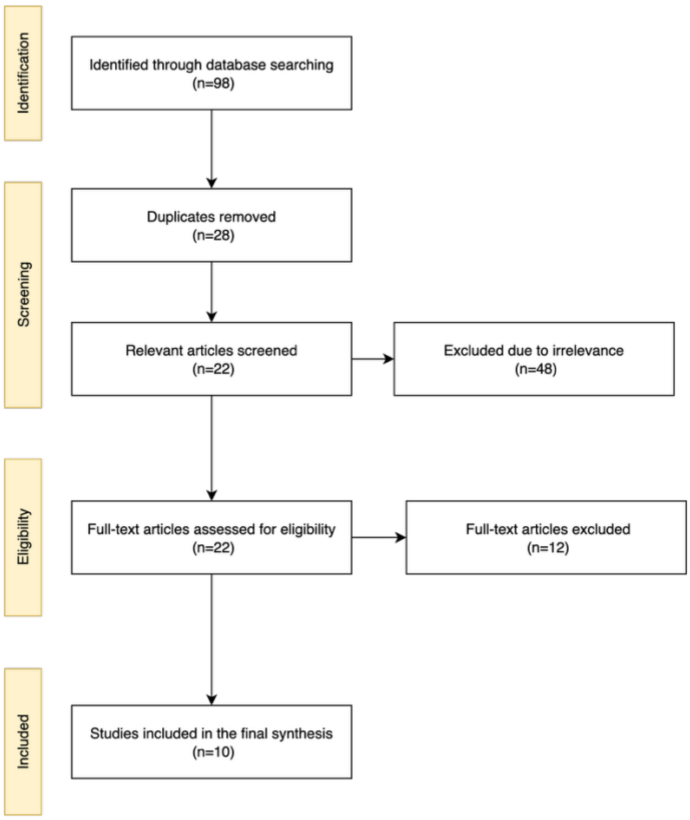

Figure 1. PRISMA Flow Diagram of the Study

To ensure quality, all selected articles were appraised using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist, and only manuscripts with a score of ≥70% were included in the final synthesis. Data were analyzed through thematic analysis, which involved a thorough reading of the selected texts, open coding, grouping codes into themes (educational level, instructional content, learning model, research method, instruments used, and research findings), and synthesizing these into thematic conclusions. To maintain the validity of findings, the analysis adhered to strict procedures, ensured traceability to original sources, applied literature triangulation, and complied with established ethical standards in scientific publication.

RESULTS AND DISCUSSION

This study analyzed ten peer-reviewed publications from 2019 to 2024 to assess the impact of STEAM-based instruction on critical thinking development among students. The findings, detailed in Table 1, are categorized by academic level, instructional topic, pedagogical model, research approach, employed instruments, and observed outcomes.

Based on Educational Level

The review of ten selected articles reflects the implementation of the STEAM approach across various educational levels, ranging from primary school (SD), junior high school (SMP/MTs), senior high school (SMA), to Islamic senior high school (MA). At the primary level, studies focused on Science and Social Studies (IPAS) with topics such as electricity (J3) and living organisms (J4). At the junior high school level, the topics included environmental pollution (J9) and plant structure and function (J10). At the MTs level, research was centered on light and optical instruments (J6). Meanwhile, at the senior high school level, studies emphasized physics, including heat transfer (J1) and sound waves (J7), as well as chemistry on electrolyte and non-electrolyte solutions (J5). In the Islamic senior high school context (MA), the STEAM approach was applied to biology instruction (J8).

Based on Instructional Content

The learning materials employed in the reviewed studies varied widely and were thematically relevant to real-life phenomena. At the primary level, materials included electricity (J3) and living organisms (J4) within IPAS. At the junior high level, topics addressed environmental issues (J9) and plant structure (J10). Research at the MTs level focused on light and optics (J6), while studies at the senior high level covered physics topics such as heat transfer (J1) and sound waves (J7), as well as electrolyte chemistry (J5). At the MA level, biology served as the primary subject context for implementing the STEAM approach (J8).

Based on Learning Model and Research Method

Almost all studies integrated Project-Based Learning (PjBL) as the core instructional model within the STEAM framework. A variety of research methodologies were applied, including quasi-experimental designs at the SMA (J1, J5, J7) and MA (J8) levels, classroom action research (CAR) at the SD (J4) and SMP (J10) levels, and descriptive qualitative studies at the SD level (J2, J3). Notably, in the context of sound wave instruction in physics, one study employed a Research and Development (R&D) approach (J7).

Based on Research Instruments

A wide array of instruments was used to assess students' critical thinking skills and related constructs. These included critical thinking tests (J1, J5, J8, J9), observation sheets (J2, J3, J4, J6, J7), questionnaires (J1, J3, J5, J6, J7), interview guides (J2, J3), assessment rubrics (J10), and documentation (J1, J2, J3, J6). Additionally, one study incorporated a self-efficacy questionnaire to explore broader impacts of STEAM-based instruction (J5).

Table 1. Summary of Reviewed Articles on the Effect of STEAM Approach on Students' Critical Thinking Skills (2019–2024)

Code	Authors	Level	Subject Matter	Learning Model	Methodology	Instruments	Findings
J1	Liah et al. (2024)	Senior High	Physics – Heat Transfer	PjBL	Quantitative – Quasi-experimental	Critical thinking test, questionnaire, documentation	Significant improvement in critical thinking (N-Gain: experiment = 0.76; control = 0.34)
J2	Fitriana et al. (2024)	Primary	Science and Social Studies (IPAS)	PjBL	Descriptive qualitative	Observation sheet, interview guide, documentation	Improvement in critical thinking and entrepreneurial skills
J3	D. P. Sari et al. (2023)	Primary	IPAS – Electricity	PjBL	Descriptive qualitative	Observation sheet, questionnaire, documentation, interview guide	Improved students' critical and creative thinking skills
J4	L. E. Sari (2023)	Primary	IPAS – Living Beings	PjBL	Classroom action research (2 cycles)	Observation sheet, questionnaire	Increased learning interest (78.03% to 80.30%) and critical thinking (59.13% to 79.9%)
J5	Rusmansyah et al. (2023)	Senior High	Chemistry – Electrolyte Solutions	PjBL	Quasi-experimental	Critical thinking test, self-efficacy questionnaire	Improved critical thinking (N-Gain = 0.58) and self-efficacy (N-Gain = 0.75)
J6	Khoiriyyah et al. (2022)	Junior High (MTs)	Science – Light and Optics	PjBL	Pre-experimental design	Observation sheet, test items, questionnaire, documentation	Improved critical thinking (from 35.45% to 62.73%)
J7	Lestari (2021)	Senior High	Physics – Sound Waves (Musical Tool Prototype)	PjBL	R&D	Test items, questionnaire, observation sheet	Improved 21st-century skills (critical thinking N-Gain = 0.54)
J8	Fitriyah & Ramadani (2021)	Islamic Senior	Biology	PjBL	Quasi-experimental	Essay test, observation sheet	Improvement in critical thinking

Code	Authors	Level	Subject Matter	Learning Model	Methodology	Instruments	Findings
		High (MA)					
J9	Priantari et al. (2020)	Junior High	Science – Environmental Pollution	PjBL	True experimental	Test items	Improvement in critical thinking
J10	Yanti (2020)	Junior High	Science – Plant Structure & Function	Goolital-Ject	Classroom action research (2 cycles)	Test items, scoring rubric	Improvement in critical thinking

Based on Research Findings

Overall, the findings suggest that the implementation of STEAM-based instruction, particularly through the PjBL model, positively contributed to the development of students' critical thinking skills across educational levels. At the primary level, improvements in critical thinking were accompanied by increases in creativity, learning motivation, and entrepreneurial skills (J2, J3, J4). At the junior high school level, significant gains in critical thinking were reported, particularly in the contexts of environmental pollution (J9) and plant structure (J10). In the MTs context, a positive shift was observed in students' critical thinking skills when engaging with light and optics (J6). At the senior high school level, in addition to gains in critical thinking, studies reported improved self-efficacy in electrolyte chemistry (J5) and strengthened 21st-century skills through physics-based projects on sound waves (J7). At the MA level, the use of PjBL within STEAM was found effective in enhancing critical thinking in biology learning (J8).

The synthesis of the ten reviewed studies affirms that the STEAM approach—particularly when integrated with Project-Based Learning—is generally consistent in its positive contribution to the development of students' critical thinking abilities. However, the degree of effectiveness varied depending on educational level, subject matter, and school context. In addition to promoting critical thinking, STEAM-based instruction was also found to positively influence other dimensions such as creativity, student engagement, self-efficacy, entrepreneurship, and 21st-century skills. These findings highlight that STEAM is not merely a pedagogical strategy, but rather an educational practice that reflects the dynamic interplay between students, teachers, and the sociocultural environment of the school.

Contextual Effectiveness Across Educational Levels

Differences in outcomes across educational levels reveal the contextual nature of STEAM's effectiveness. At the primary school level, critical thinking tends to develop in tandem with creativity, learning motivation, and entrepreneurial traits. This suggests that young learners respond better to project-based instruction when it is integrated with play-based or exploratory activities (Aulia et al., 2022; Fitriyah & Ramadani, 2021). In other words, STEAM implementation at this level is most effective when grounded in students' everyday experiences.

Conversely, at the senior high school and MA levels, STEAM appears more effective in promoting complex and reflective critical thinking skills. For instance, Rusmansyah et al. (2023) reported improvements not only in students' critical thinking but also in their self-efficacy, while Lestari (2021) highlighted the enhancement of 21st-century competencies through a physics-based musical instrument project. This higher level of effectiveness may be attributed to students' greater cognitive maturity and prior familiarity with project-based learning models, which enable them to analyze, evaluate, and construct evidence-based arguments more effectively (Mayla et al., 2024).

At the junior high school (SMP) and MTs levels, the STEAM approach serves as a bridge between conceptual understanding and analytical skill development. Studies on environmental pollution and optics demonstrate that science projects help students interpret both natural phenomena and environmental issues (Rusmansyah et al., 2023). However, research conducted in madrasah contexts revealed that limited infrastructure poses challenges to optimal implementation. Khoiriyyah et al. (2022) emphasized that, although critical thinking skills did improve, the lack of adequate resources led to less significant gains compared to those in well-equipped schools. This underscores the influence of socio-economic context in determining the effectiveness of STEAM-based instruction.

Theoretical and Practical Implications

The dominance of PjBL across the reviewed studies aligns with constructivist learning theory, which posits that knowledge is constructed through experience and social interaction (Salsabila & Muqowim, 2024). The use of diverse research methodologies—from quasi-experimental designs to classroom action research and R&D—demonstrates the methodological flexibility of STEAM while consistently yielding positive trends in outcomes. The variety of instruments, including critical thinking tests, observations, questionnaires, interviews, rubrics, and self-efficacy scales, reflects a recognition that critical thinking is a multidimensional construct encompassing cognitive, affective, and social domains (Juliyantika & Batubara, 2022).

Findings from the madrasah context offer a compelling perspective: resource limitations can foster alternative forms of creativity and resilience. Both teachers and students utilized simple tools to sustain project-based learning, highlighting the adaptive capacity of education in the face of structural inequities. From a reflective standpoint, this suggests that improvements in critical thinking are not solely driven by pedagogical design, but also emerge from students' adaptive responses to environmental constraints. Researchers, particularly those from academic institutions, must recognize that interpretations of "improvement" can differ significantly when viewed through the lens of students who regularly navigate limited resources.

From a theoretical standpoint, this study contributes to science education literature by emphasizing that the effectiveness of STEAM is highly contextual—with higher gains observed at the senior high school and MA levels, and more consistent results in schools with adequate facilities compared to under-resourced madrasahs. This broadens prior studies that often highlight the benefits of STEAM without adequately addressing variations across contexts. From a practical perspective, the findings highlight the need for context-sensitive adaptations: in primary education, STEAM should be integrated with play and simple explorations, whereas in secondary education, more complex, analytically challenging projects are appropriate. Moreover, equitable access to educational resources and enhanced teacher training are essential to ensure that the benefits of STEAM can be realized across diverse educational environments.

CONCLUSION

The analysis of ten selected articles revealed that approximately 90% of the studies reported a significant improvement in students' critical thinking skills through the implementation of Project-Based Learning (PjBL) integrated with STEAM. The most notable outcomes were observed at the senior high school level, particularly in subjects such as Physics and Biology. At the primary school level, the effectiveness of the STEAM approach was maximized when combined with play-based or exploratory activities. In junior high schools (SMP and MTs), STEAM functioned as a bridge between conceptual understanding and the development of analytical skills. These findings underscore that the effectiveness of STEAM is highly contextual—not solely determined by instructional design, but also influenced by students' cognitive readiness, the role of teachers, and the socio-economic conditions of the school environment. From a practical perspective, this study highlights the importance of: Encouraging teachers to implement PjBL-STEAM as a means to enhance students' problem-solving abilities, urging policymakers to provide structured support in the form of teacher training and equitable distribution of educational resources, and recommending that future researchers conduct cross-study effect size analyses to obtain a more comprehensive and quantitative understanding of STEAM's impact across different contexts.

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