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LITERATUR REVIEW ARTICLE

Effectiveness of STEM-Based Physics Learning in Fostering Critical Thinking Skills at the Senior High School Level: A Systematic Literature Review

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Abstract

21st century competencies require students to develop strong critical thinking abilities, especially in physics education, which emphasizes conceptual understanding and problem solving. The STEM approach has emerged as an innovative solution to connect physics concepts with real world applications through experiments, problem solving, and product design. However, findings from previous studies remain scattered and have not been systematically synthesized regarding their magnitude and specific outcomes. This study therefore aims to analyze the effectiveness of STEM learning in improving students' critical thinking skills in physics at the senior secondary level, using a Systematic Literature Review following PRISMA guidelines. This study reviewed 20 SINTA indexed national articles published between 2015 and 2025 were reviewed and analyzed. The results show that STEM based learning significantly improves critical thinking skills, with normalized gain (N gain) values ranging from 0.16 to 0.94, falling mostly in the moderate to high category. Effectiveness is strongest when STEM is integrated with Problem Based Learning (PBL) or Project Based Learning (PjBL). These findings provide evidence based recommendations for curriculum design and instructional strategies in physics education, supporting the development of more effective STEM integrated learning programs to foster higher order thinking skills among secondary students.

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INTRODUCTION

The development of information and communication technology in the digital age requires students to master 21st-century competencies, particularly critical thinking, communication, collaboration, and creativity (Septikasari & Frasandi, 2018). This demand is supported by UNESCO (2021) and Hammond (2022), who emphasize that modern education must equip learners to solve complex, interdisciplinary problems and produce innovative solutions. Unlike previous eras, the 21st century work and social environment demands higher order thinking, as routine tasks are increasingly automated (Wijaya et al., 2016). In this context, critical thinking becomes one of the most essential competencies because it enables students to interpret information logically, test assumptions, and make reasoned decisions in academic and real-life situations (Kusyanto et al., 2022; Kramer et al., 2024).

Among these competencies, critical thinking is the most emphasized yet challenging to develop. Various studies indicate that Indonesian students' critical thinking abilities remain relatively low, largely due to limited reading literacy and teacher-centered instruction that does not encourage in-depth analysis of information (Umroh et al., 2024; Hidayah & Fitriani, 2021). This condition is reinforced by the 2022 PISA results, which recorded Indonesia's reading literacy score dropping to 359, the lowest achievement since Indonesia's participation, indicating that students have not been equipped with adequate higher-order thinking skills. At the global level, STEM education in various countries still faces significant challenges because it has not been able to effectively cultivate higher-order thinking skills. Students are often not guided to analyze problems in depth, ask critical questions, and evaluate solutions scientifically (Kramer et al., 2024). Many educators are unfamiliar with the STEM approach, requiring specialized training and mentoring. Furthermore, limited facilities, such as science laboratories, technological devices, or teaching aids, are also obstacles in many schools, especially in remote areas. Curricula that do not fully support STEM integration exacerbate this challenge and need to be addressed for effective implementation (Siregar & R, 2025). This condition emphasizes the need for innovative learning that not only focuses on delivering material but also provides space for students to be active, explore, and construct knowledge.

However, existing reviews remain insufficient and do not fully address the specific intersection of STEM and physics learning. Previous works are either too broad, outdated, or lack focused analysis. For instance, Roslina et al. (2022) reviewed 36 international studies published between 2015 and 2022, but their findings are general, do not present quantitative measures such as effect size or normalized gain, and do not focus specifically on physics education or the Indonesian context. Similarly, Diyana & Sabila (2025) analyzed 12 Scopus-indexed articles, yet their review is limited to global trends, does not compare the effectiveness of different STEM models, and does not identify which physics topics are most suitable for STEM integration. Most importantly, no recent systematic review has synthesized studies published after 2022, meaning current evidence is partially outdated. Consequently, existing evidence cannot adequately inform teachers and curriculum developers regarding which STEM instructional models consistently produce the greatest improvement in students' critical thinking skills across different physics topics. Furthermore, no study has specifically examined how STEM influences critical thinking within the unique context of Indonesian physics education using nationally

accredited research indexed in SINTA (Diyana & Sabila, 2025). This gap means educators and policymakers lack precise, up-to-date, and context-specific evidence to guide curriculum design and teaching practice. As a result, educational stakeholders still lack evidence-based guidance for selecting effective STEM approaches that are appropriate for Indonesian secondary physics classrooms.

Therefore, this study addresses these limitations by presenting a systematic literature review following PRISMA guidelines, analyzing 20 SINTA-indexed national articles published between 2015 and 2025. It aims to evaluate the effectiveness of STEM learning in enhancing senior high school students' critical thinking skills in physics, including the magnitude of improvement, most suitable learning models, and relevant physics content. The findings are expected to fill the existing gap by providing comprehensive and up-to-date evidence regarding the effectiveness of STEM learning in improving critical thinking skills across different physics topics and instructional models within the Indonesian context.

METHOD

This study used the Systematic Literature Review (SLR) design based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The SLR approach was chosen to systematically identify, screen, select, and synthesize previous empirical studies examining the implementation of STEM-integrated learning to improve students' critical thinking skills in physics learning. The purpose of this review was not to conduct a statistical meta-analysis, but to provide a structured and evidence-based narrative synthesis of relevant quantitative findings.

Search Strategy

This study was conducted in 2025 through a database search using Google Scholar. The review focused on articles published in SINTA-indexed national journals within the period 2015-2025, with searches using a combination of the keywords "STEM learning," "high school physics," and "critical thinking." Table 1 shows the search strategy used.

Table 1. Search Strategy

Data Base	Google Scholar SINTA
Search	Keywords: "STEM learning", "physics", "senior high school", "critical thinking"
Publication period	2015-2025
Data is accessed	October 2025

Screening Criteria

The articles found were selected using inclusion and exclusion criteria to ensure that only relevant and eligible studies were analyzed. Articles that met the inclusion criteria were retained for further screening, while those that met the exclusion criteria were separated and discarded. The inclusion and exclusion criteria are shown in Table 2.

Table 2. Inclusion and Exclusion Criteria

Inclusion Criteria		Exclusion Criteria	
IC 1:	The research topic discusses STEM learning in improving the critical thinking skills of physics students.	EC 1:	Articles that are not fully accessible
IC 2:	Publication year between 2015-2025 indexed by SINTA	EC 2:	Articles that do not meet one of the inclusion criteria
IC 3:	Quantitative research with N-gain values		
IC 4	Research subject High school level		

Data Extraction and Analysis

The article search was conducted using Google Scholar with a combination of keywords: "STEM learning," "high school physics," and "critical thinking." The search focused on articles published between 2015 and 2025. The articles obtained were then selected based on the established inclusion and exclusion criteria, resulting in 20 articles for further analysis. All data were analyzed descriptively using a narrative synthesis approach to produce a comprehensive picture of the effectiveness of STEM learning in physics lessons.

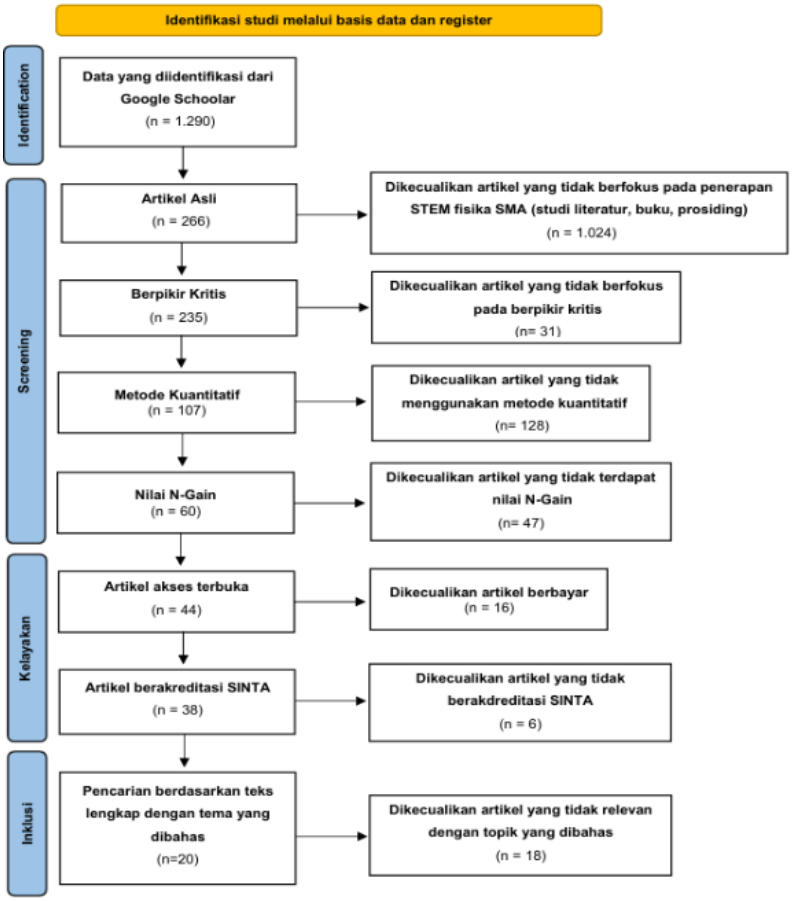

Figure 1. Diagram PRISMA

RESULT AND DISCUSSION

This study analyzed 20 articles related to the effectiveness of STEM learning in improving students' critical thinking skills in physics lessons.

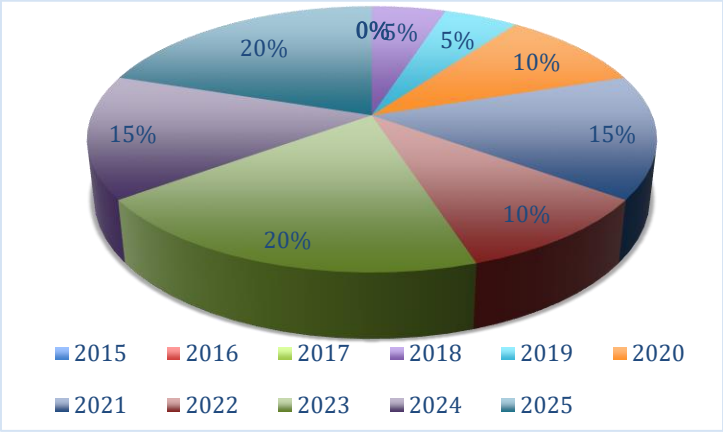

Figure 2. Number of articles published since 2015-2025

Based on Figure 2, shows the number of research publications from 2015 to 2017, where no articles relevant to the research criteria were found. From 2018 to 2019, one article was found, while in 2020 and 2022, two articles were found. The following year, from 2021 to 2024, three articles relevant to the criteria were found. Meanwhile, in 2023 and 2025, four articles were found. These data demonstrate that between 2015 and 2025, research discussing the application of STEM to physics students' critical thinking skills was most frequently published in 2021, 2023, 2024, and 2025. All articles obtained used a quantitative research approach. The summary and analysis results of 20 articles on the research topic are presented in Table 4.

Table 4. Review Results

No	Identity Article	N-Gain (Category)	Physical Material	Learning Strategy
1	Nisah et al.. (2024). *Optimizing of Physics Learning through PjBL-STEM Model to Improve Critical Thinking Skills and Students' Responsibility Attitudes. Journal of Science Education Research (JPPIPA).* (SINTA 2)	0.67 (Medium)	Light Waves	PjBL-STEM

2	Anggraini et al., (2025). Improving Students' Critical Thinking Skills in Renewable Energy through PjBL-STEM with Design Thinking. Journal of Mathematics and Science Education. *Journal of Mathematics and Science Education* (JPMS). (SINTA 2)	0,49 (Medium)	Renewable Energy (X SMA)	PjBL-STEM
3	Yusra et al., (2025). The Effect of PjBL-STEM on Improving Critical Thinking Skills in Renewable Energy Material in Supporting Quality Education. The Effect of PjBL-STEM on Improving Critical Thinking Skills in Renewable Energy Material in Supporting Quality Education. *Journal of Mathematics and Science Education.* (SINTA 2)	0.36 (Medium)	Renewable Energy (X SMA)	PjBL-STEM
4	Setiana & Madlazim. (2021). Application of the Integrated STEM 7E Learning Cycle Model to Improve Students' Critical Thinking Skills in Global Warming Material. *Innovation in Physics Education.* (SINTA 4)	0,72 (High)	Global Warming (XI MIPA)	Learning Cycle 7E-STEM
5	Putri et al., (2020). ntegrated STEM Problem-Based Learning in the Covid-19 Pandemic Era to Improve Students' Critical Thinking Skills. *Journal of Science and Science Learning.* (SINTA 2)	0,72 (Medium)	Renewable Energy	PBL-STEM
6	Lestari & Muhajir. (2021). The STEM Approach to Improving Students' Critical Thinking Skills in Static Fluid Materials. *Journal of Education and Physics (JPIF).* (SINTA 5)	0,62 (Medium)	Statics Fluids	STEM
7	Yulianti, N. K. D. (2023). Developing Critical Thinking Skills Through STEM-Based Physics Learning Using Gas Kinetic Theory. *Wahana Pendidikan Fisika. (*SINTA 4)	0,40 (Medium)	Gas Kinetic Theory	PBL-STEM

8	Rosyidah et al., (2020). Students' Critical Thinking Skills through the STEM-PjBL Model Accompanied by Authentic Assessment in Static Fluid Material. *Journal of Education: Theory, Research, and Development.* (SINTA 3)	0,16 (Low)	Statics Fluids	PjBL-STEM
9	Eris et al., (2024). Application of the Integrated STEM Problem-Based Learning Model on Critical Thinking Skills in Archimedes' Principle Material. *JPF (Journal of Physics Education) FKIP UM Metro).* (SINTA 3)	0,77 (High)	Archimedes' Principle	PBL-STEM
10	Sumardiana et al., (2019). Critical Thinking Skills in Project-Based Learning Models with STEM for High School Students on Temperature and Heat. *Journal of Education: Theory, Research, and Development.* (SINTA 3)	0,43(Medium)	Temperature and Heat	PjBL-STEM
11	Awaludin & Makiyah. (2025). *The Effect of the PBL-STEM on Students' Critical Thinking Skills. Journal of Physics Education and Technology (JPFT).* (SINTA 3)	0,72 (High)	Renewable Energy	PBL-STEM
12	Khoirunnissa et al., (2024). *The Implementation of STEM-PBL Learning to Enhance Students' Critical Thinking Skills. Journal of Physics Education and Technology (JPFT).* (SINTA 3)	0,5 (Medium)	Temperature and Heat	PBL-STEM
13	Rohmah et al. (2021). The Application of STEM-Based Problem-Based Learning in Optical Instrument Material to Improve Students' Critical Thinking Skills. *Journal of Physics Learning Research.* (SINTA 3)	0,25 (Low)	Optical Instruments	PBL-STEM
14	Adhelacahya & Suswanto. (2023). *The Impact of*	0,76 (High)	Mechanical Waves	PBL-STEM

	Problem-Based Learning Electronics Module Integrated with STEM on Students' Critical Thinking Skills. Journal of Science Education Research (JPPIPA UNRAM). (SINTA 2)			
15	Khoiriyah et al., (2018). Implementation of STEM Learning Approach to Improve Critical Thinking Skills of High School Students on Sound Wave Material. *Journal of Physics Education Research and* Studies *(JRKPF*). (SINTA 3)	0,63 (Medium)	Sound Waves	STEM Murni
16	Zulfawati et al. (2022). The Effectiveness of Problem-Based Learning with Integrated STEM Approach in Improving the Critical Thinking Skills. *Jurnal Penelitian Fisika dan Aplikasinya (JPFA), 12(1).* SINTA 2	0,28 (Low)	Momentum and Impulse	PBL-STEM
17	Mardiana et al. (2023). Enhancing Critical Thinking Skills Through Android-Assisted Virtual Physics Learning: A Focus On Hots Development. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi, 9(2).*	0,74 (High)	Optical Instruments	STEM
18	Monika et al. (2023). Effectiveness of Science Technology Engineering Mathematics Problem Based Learning (STEM PBL) and Science Technology. *Jurnal Penelitian Pendidikan IPA, 9(11).* SINTA 2Engineering Mathematics Project Based Learning (STEM PjBL) to Improve Critical Thinking Ability	0,76 (High)	Light Waves	PBL-STEM
19	Julaila et al. (2023). The Impact of MLM-STEM on Temperature and Heat Material in Students' Critical	0,71 (High)	Temperature and Heat	MLM-STEM

	Thinking Skills. *Jurnal Pendidikan MIPA.* SINTA 2			
20	Isra et al. (2025). Enhancing Critical Thinking Skill through STEM E-LKPD Assisted by Liveworksheets. *EduFisika: Jurnal Pendidikan Fisika.* SINTA 3	0,94 (High)	Renewable Energy	STEM

Based on the analysis results, it shows that STEM-based learning has a positive effect on improving students' critical thinking skills in physics learning. Most articles report moderate N-gain values, while several other articles report high increases, and two of them report low increases. These findings directly address the research objective, which is to demonstrate the effectiveness of various STEM learning models and strategies in improving students' critical thinking skills in physics lessons. The findings are in line with the opinion of Kusyanto et al. (2022), who state that the STEM approach is designed to equip students with 21st-century competencies, including critical thinking skills as a very important aspect.

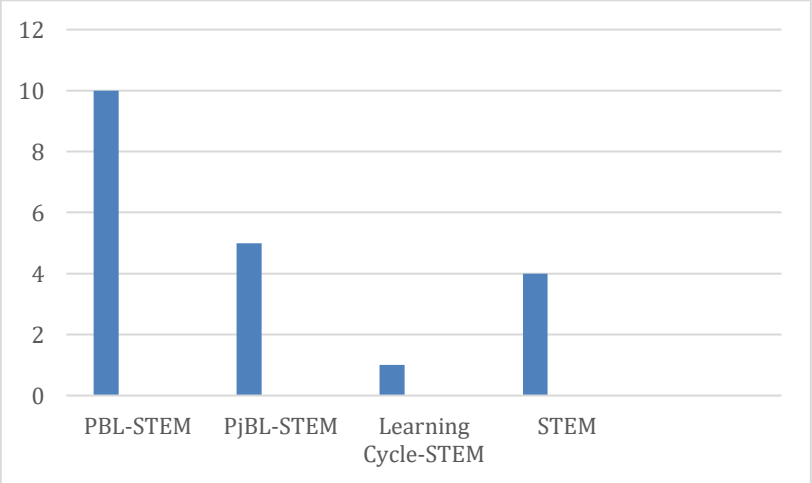

Figure 3. Distribution of STEM Learning Models

Based on Figure 3, the most dominant learning strategy is the use of the PBL-STEM model with 20 articles and PjBL-STEM with 5 articles. Another model used in STEM learning, namely the 7E Learning Cycle, was found in 1 article and the other 4 articles only used the STEM approach without being inspired by other learning models, but were integrated with STEM-based learning media.

Based on the analysis, STEM-based physics learning has generally been shown to improve students' critical thinking skills. The N-gain scores obtained were mostly in the moderate to high category, although some studies have shown improvements in the low category. This trend confirms that STEM learning has significant potential in developing students' critical thinking skills in physics. A total of 9 research articles shows an increase in students' critical thinking skills in the high category. These results generally indicate that the application of STEM learning in physics lessons can provide a more meaningful learning experience. STEM learning can encourage active student involvement in the

problem-solving process, concept analysis, and decision-making (Putri et al., 2020). Most others show improvements in the moderate category, which generally indicates that students are able to understand problems and identify relevant information, but still experience obstacles in the evaluation and reflection stages of the resulting solutions (Yulianti, 2023 & Sumardiana et al., 2019). The relatively low level of critical thinking skills is generally due to the teacher's dominant role in the learning process, time constraints, and technical obstacles in implementing online learning, such as unstable network connections and minimal direct interaction between students. Furthermore, the lack of explicit assessment instrument design also contributes to the low results, as it does not reflect students' true critical thinking abilities.

The most dominant STEM-based learning models used are Problem-Based Learning (PBL-STEM) and Project-Based Learning (PjBL-STEM), in addition to the 7E Learning Cycle model and STEM learning combined with media such as live worksheet-based e-LKPD, MLM-STEM, and local wisdom-based virtual media. The implementation of these models has generally been proven to improve students' critical thinking skills, with N-gain scores mostly in the moderate to high category. The highest gains were achieved through student-centered learning, active involvement in contextual problem-solving, and the use of innovative learning media.

The physics materials used were quite diverse, with Renewable Energy and Temperature and Heat dominating, both of which showed moderate to high gains. Other materials such as Waves, Fluid Statics, Optical Instruments, Global Warming, and Archimedes' Law were also used. While materials with a high level of abstraction, such as the Kinetic Theory of Gases and Momentum and Impulse, tended to produce lower gains because students struggled to relate the concepts to real-world situations.

The results of this review align with global research regarding STEM and physics instruction. Studies from around the world confirm that when students participate in hands-on, inquiry-driven, or design-focused activities, STEM-based physics lessons effectively strengthen analytical thinking, problem-solving abilities, and the ability to link theoretical concepts with real-world applications. As noted by Palmgren et al. (2023), building connections between mathematical skills and conceptual knowledge is essential for developing integrated reasoning in physics. Likewise, Subramaniam et al. (2025) found that having students create and solve problems through engineering design tasks encourages deeper levels of thinking, such as analysis and evaluation. Even so, Kramer et al. (2024) point out that across many countries, putting STEM into practice remains difficult; the goal of interdisciplinary learning is often not fully translated into classroom activities that truly develop higher-order thinking skills. In this regard, this study adds to the existing global evidence by demonstrating that in the Indonesian educational setting, combining STEM with student-centered approaches like Problem-Based Learning and Project-Based Learning yields the best results.

CONCLUSION

Based on an examination of 20 SINTA-accredited national articles published between 2015 and 2025, this review shows that STEM-based learning is effective in improving students' critical thinking skills in physics, with most studies reporting improvements in the moderate to high categories, some in the medium category, and three studies in the

low category. The physics materials used are diverse and dominated by Renewable Energy and Temperature and Heat, followed by other materials such as Light Waves, Work and Energy, Static Fluids, Optical Instruments, Global Warming, Kinetic Theory of Gases, Sound Waves, Mechanical Waves, Archimedes' Law, and Momentum and Impulse. The most widely implemented learning strategies are Problem-Based Learning and Project-Based Learning integrated with STEM which effectively train students' active engagement, collaboration, and higher-order thinking skills, as well as the 7E-STEM Learning Cycle and a pure STEM approach integrated with STEM-based interactive learning media.

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