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THE ROLE OF STEM EDUCATION IN DEVELOPING 21ST-CENTURY SKILLS: A LITERATURE REVIEW

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Abstrak

The rapid development of 21st-century skills demands a transformation in science education, particularly in physics learning at the senior high school level. However, many studies report that physics learning in Indonesia is still dominated by teacher-centered approaches, resulting in suboptimal development of critical thinking, creativity, collaboration, and problem-solving skills. This indicates a research gap in synthesizing how STEM (Science, Technology, Engineering, and Mathematics) education contributes to the development of 21st-century skills within physics learning contexts. Therefore, this study aims to analyze and synthesize the role of STEM education in enhancing 21st-century skills in senior high school physics learning. This research employed a qualitative descriptive approach using a literature review method. The data source consisted of 15 national journal articles published within the last five years, selected through purposive sampling based on relevance to STEM education, physics learning, and 21st-century skills. Data were analyzed using content analysis and thematic synthesis techniques to identify patterns and relationships among variables. The findings indicate that STEM education consistently contributes to improving students' critical thinking, creativity, communication, collaboration, and Higher Order Thinking Skills (HOTS). Furthermore, the integration of STEM with Project-Based Learning (PjBL), Problem-Based Learning (PBL), and digital learning media significantly enhances scientific literacy and digital literacy. The study concludes that STEM education plays a crucial role in fostering 21st-century skills holistically in physics learning, making it highly relevant for implementation in senior high school education.

INTRODUCTION

Advances in science and technology during the Fourth Industrial Revolution and the transition toward Society 5.0 have brought significant changes to the world of education. The education system is no longer focused solely on mastering concepts, but also on developing the skills students need to face the challenges of the 21st century. These skills include critical thinking, creativity, communication, collaboration, digital literacy, problem-solving, and the ability to adapt to technological advancements. Therefore, science education—particularly physics at the high school level—is required to facilitate the development of these competencies so that students are prepared to face increasingly complex social, economic, and technological changes (Khalishah & Mahmudah, 2022; Fadillah, 2024; Mustamiin et al., 2026).

Physics is a branch of science characterized by the study of natural phenomena through scientific inquiry, experimentation, mathematical analysis, and problem-solving. These characteristics make physics education highly effective for developing higher-order thinking skills (HOTS), investigative skills, creativity, and problem-solving abilities. However, various studies indicate that the physics learning process in schools is still dominated by conventional, teacher-centered instruction, resulting in students spending more time memorizing concepts rather than developing critical thinking skills or 21st-century skills (Maghfirah et al., 2025; Hayat, 2024).

One approach considered capable of addressing these challenges is STEM (Science, Technology, Engineering, and Mathematics) education. The STEM approach integrates concepts from science, technology, engineering, and mathematics into a learning process that is contextual, problem-solving-based, and oriented toward real-life situations. This integration enables students not only to understand scientific concepts theoretically but also to apply their knowledge to design solutions to various problems they face. Consequently, learning becomes more meaningful while fostering the development of critical thinking, creativity, collaboration, communication, and technological literacy as part of 21st-century skills (Muttaqiin, 2023; Khalishah & Mahmudah, 2022; Fadillah, 2024).

In the context of physics education, the implementation of STEM is increasingly being developed through various innovative learning models, such as Project-Based Learning (PjBL), Problem-Based Learning (PBL), project-based learning, and the use of interactive multimedia. This integration aims to create active, collaborative, and student-centered learning experiences. Research by Megawati et al. (2023) shows that integrating Project-Based Learning with a STEM approach positively contributes to enhancing students' critical thinking, creativity, communication, and collaboration skills. Similar results were also reported by Roslina et al. (2022), who found that the implementation of STEM-PjBL effectively improves physics learning outcomes while developing various 21st-century competencies.

In addition to project-based learning models, the implementation of Problem-Based Learning (PBL) integrated with STEM also has a positive impact on students' ability to systematically solve scientific problems. A literature review conducted by Lestari et al. (2025) shows that various implementations of PBL in high school physics instruction consistently enhance students' critical thinking, problem-solving, scientific communication, and collaboration skills. On the other hand, the development of STEM-based interactive e-multimedia has also proven to be an effective innovation in enhancing

students' science literacy, digital literacy, and 21st-century skills, as it provides a more engaging and interactive learning experience (Widya et al., 2024).

Various literature reviews and meta-analyses have further reinforced findings regarding the effectiveness of STEM education in physics learning. Putri et al. (2025), through a systematic literature review of studies conducted from 2014 to 2025, concluded that STEM integration has a positive impact on students' cognitive abilities in physics learning. In line with this, Yulianti et al. (2025) identified that the trend in STEM research in Indonesia shows a fairly rapid increase, with a predominance of studies focused on improving critical thinking skills, creativity, problem-solving, and physics learning outcomes. Sulistyawan and Masturi (2025), through a meta-analysis, also demonstrated that project-based physics learning has a significant effect on improving students' higher-order thinking skills and 21st-century competencies.

Although various studies have demonstrated the effectiveness of STEM implementation in physics education, most research still focuses on testing specific instructional models, the effectiveness of instructional media, or improving learning outcomes in experimental contexts. Comprehensive reviews that integrate various research findings on the role of STEM education in developing 21st-century skills in high school physics education remain relatively limited. In fact, a synthesis of various research findings is essential to obtain a more comprehensive picture of the development of STEM implementation, the 21st-century skills most frequently developed, the dominant learning approaches used, and the direction of future research (Putri et al., 2025; Yulianti et al., 2025).

Based on the above discussion, this study was conducted using a literature review method to systematically examine various research findings regarding the role of STEM education in developing 21st-century skills in science education, particularly physics at the high school level. The results of this study are expected to provide a comprehensive overview of the effectiveness of STEM implementation and trends in research, as well as serve as a reference for teachers, researchers, and policymakers in designing physics instruction capable of developing students' competencies in line with the demands of the 21st century.

LITERATURE REVIEW

A. STEM Education

STEM (Science, Technology, Engineering, and Mathematics) education is an integrated learning approach that combines these four major disciplines within a contextual, problem-solving-based learning process. This approach is designed to help students connect theoretical concepts with real-life applications, thereby making learning more meaningful (Muttaqiin, 2023; Fadillah, 2024).

Conceptually, STEM focuses not only on mastering concepts but also on developing 21st-century skills such as critical thinking, creativity, communication, and collaboration. Interdisciplinary integration in STEM enables students to learn through the processes of investigation, experimentation, and designing solutions to real-world problems (Khalishah & Mahmudah, 2022; Mustamiin et al., 2026).

In its implementation, STEM places students at the center of learning (student-centered learning), with teachers serving as facilitators. Students are encouraged to actively explore, analyze, and solve problems—both independently

and collaboratively—through project-based and problem-solving activities (Fadillah, 2024).

The implementation of STEM has also been shown to enhance higher-order thinking skills because students not only understand concepts but also analyze, evaluate, and create solutions based on scientific knowledge (Maghfirah et al., 2025). Furthermore, STEM contributes to improving science and technology literacy, which are essential for navigating the development of a knowledge-based society (Rosyidah et al., 2026).

Research findings indicate that the implementation of STEM in physics education in Indonesia continues to increase and is often combined with instructional models such as Project-Based Learning, Problem-Based Learning, and technology-based learning media. Research findings indicate that this approach is effective in enhancing conceptual understanding, critical thinking skills, and student learning outcomes (Putri et al., 2025; Yulianti et al., 2025; Widya et al., 2024).

In the context of science education, particularly high school physics, STEM is highly relevant because it supports learning that is experimental, analytical, and grounded in real-world phenomena. This makes STEM an approach capable of bridging the gap between theoretical concepts and practical applications in everyday life (Hayat, 2024).

Overall, STEM education is a learning approach that integrates knowledge, skills, and technology to foster active, contextual learning focused on developing students' 21st-century competencies.

B. Physics Education at the High School Level

Physics education at the high school level is a learning process aimed at developing students' conceptual understanding, scientific process skills, and higher-order thinking skills in explaining natural phenomena scientifically. Physics requires students not only to understand theory but also to be able to conduct observations, experiments, data analysis, and problem-solving in a systematic manner (Hayat, 2024; Maghfirah et al., 2025).

However, in practice, physics instruction is still largely dominated by conventional, teacher-centered approaches, resulting in students tending to be passive and underengaged in the process of knowledge construction. This situation results in low levels of critical thinking, creativity, and problem-solving skills among students in scientific contexts (Lestari et al., 2025; Maghfirah et al., 2025).

To address this issue, various instructional innovations have been implemented, such as Project-Based Learning (PjBL) and Problem-Based Learning (PBL). The implementation of PjBL integrated with STEM has been shown to enhance 21st-century skills through collaborative, investigative, and project-based activities (Megawati et al., 2023; Roslina et al., 2022). Meanwhile, PBL is also effective in improving students' critical thinking and problem-solving skills in physics learning (Lestari et al., 2025).

In addition to instructional models, the use of technology is also a crucial component of modern physics education. The use of STEM-based interactive e-multimedia helps students understand abstract concepts through visualization and simulation, while simultaneously enhancing digital literacy and science literacy (Widya et al., 2024).

The results of a meta-analysis indicate that project-based physics learning has a significant impact on improving higher-order thinking skills (HOTS) and 21st-century skills (Sulistyawan & Masturi, 2025). This suggests that active learning approaches are more effective than conventional teaching methods in developing students' competencies.

Furthermore, the STEM approach in physics education has also been shown to enhance conceptual understanding, as students can connect theory to real-world phenomena through experiments and contextual problem-solving (Hayat, 2024). This makes learning more meaningful and practical.

Research trends indicate that physics education today is increasingly moving toward innovative, student-centered approaches based on STEM, PBL, PjBL, and digital technology (Yulianti et al., 2025). This shift reflects a paradigm shift from teacher-centered learning toward student-centered learning.

Overall, physics instruction in high school has great potential for developing 21st-century skills when supported by innovative instructional approaches such as STEM and problem- or project-based learning models that are contextual and interactive (Fadillah, 2024; Mustamiin et al., 2026).

C. 21st-Century Skills

21st-century skills are competencies that students must possess to navigate advancements in science and technology, as well as increasingly complex global challenges. These skills emphasize not only mastery of knowledge but also critical thinking, creativity, communication, collaboration, and digital and scientific literacy (Khalishah & Mahmudah, 2022; Fadillah, 2024).

Generally, 21st-century skills are known by the 4C framework: critical thinking, creativity, communication, and collaboration. These four skills form the foundation of modern learning because they play a crucial role in developing students' ability to solve problems effectively and work together in various situations (Maghfirah et al., 2025; Lestari et al., 2025).

In addition to the 4Cs, 21st-century skills also include Higher-Order Thinking Skills (HOTS), which encompass the abilities to analyze, evaluate, and create. HOTS are particularly important in physics education because students are required to understand concepts in depth and apply them to contextual problem-solving (Maghfirah et al., 2025).

The development of 21st-century skills also encompasses science literacy, mathematical literacy, and digital literacy. Science literacy helps students understand scientific phenomena, while digital literacy supports their ability to access and process technology-based information (Widya et al., 2024; Rosyidah et al., 2026).

The 21st-century skills framework has also been expanded to the 6Cs, which include critical thinking, creativity, collaboration, communication, citizenship, and character. This framework emphasizes that education not only develops students' cognitive abilities but also their character and social responsibility (Warsito & Yasin, 2024).

In science education, 21st-century skills are also reinforced through problem-solving abilities, particularly in scientific and contextual settings. These skills are central to STEM-based learning and other innovative instructional models because students are trained to analyze problems and find solutions systematically (Putri et

al., 2025; Hayat, 2024).

Research findings indicate that the implementation of learning models such as STEM, PjBL, PBL, and interactive multimedia significantly contributes to the development of 21st-century skills, particularly in enhancing critical thinking, creativity, communication, and collaboration (Megawati et al., 2023; Yulianti et al., 2025; Widya et al., 2024).

Overall, 21st-century skills are multidimensional competencies that encompass the mutually integrated aspects of knowledge, skills, and attitudes. Developing these skills in physics education is crucial for preparing students to face global challenges rooted in technology and information (Mustamiin et al., 2026; Fadillah, 2024).

D. The Relationship Between STEM Education and 21st-Century Skills

STEM education is closely linked to the development of 21st-century skills, as this approach is designed to integrate science, technology, engineering, and mathematics into problem-solving-based learning and real-life contexts (Muttaqiin, 2023; Fadillah, 2024). This integration enables students to develop critical thinking, creativity, communication, and collaboration skills simultaneously during the learning process.

In physics education, the implementation of STEM through the Project-Based Learning (PjBL) model has proven effective in enhancing 21st-century skills through activities that require teamwork, project planning, and the resolution of real-world problems (Megawati et al., 2023; Roslina et al., 2022). Furthermore, the application of Problem-Based Learning (PBL) also makes a significant contribution to improving students' critical thinking and problem-solving skills (Lestari et al., 2025).

A review of the literature indicates that project-based learning in the context of STEM has a significant impact on improving higher-order thinking skills (HOTS) and 21st-century skills because students are actively engaged in the process of investigation and problem-solving (Sulistyawan & Masturi, 2025). This demonstrates that active learning approaches are a key factor in the development of 21st-century competencies.

The use of technology in STEM also plays a crucial role in enhancing students' digital and science literacy. The use of interactive e-multimedia enables students to understand abstract physics concepts through visualizations and simulations, thereby supporting the development of 21st-century skills more effectively (Widya et al., 2024).

Research findings also indicate that the implementation of STEM in physics instruction contributes to improvements in students' cognitive abilities and higher-order thinking skills (HOTS) through contextual learning based on real-world phenomena (Putri et al., 2025; Hayat, 2024). This reinforces the notion that STEM not only improves learning outcomes but also fosters the development of higher-order thinking skills.

Trends in educational research indicate that the integration of STEM with Project-Based Learning (PjBL), Problem-Based Learning (PBL), and digital technology is increasingly being used in physics instruction and consistently yields positive impacts on 21st-century skills (Yulianti et al., 2025). This demonstrates that

STEM has become a primary approach in 21st-century learning innovation.

Furthermore, the 6C framework—which encompasses critical thinking, creativity, collaboration, communication, citizenship, and character—further strengthens the connection between STEM and 21st-century skills, as learning focuses not only on cognitive aspects but also on the development of students' character and social competencies (Warsito & Yasin, 2024).

Overall, STEM education has a very strong and consistent relationship with the development of 21st-century skills. STEM serves as a learning approach capable of integrating knowledge, skills, and technology into a single learning process that is active, contextual, and meaningful (Mustamiin et al., 2026; Fadillah, 2024).

E. Literature Synthesis / Conceptual Framework

Based on the results of the literature review, it can be concluded that STEM education is a learning approach that integrates science, technology, engineering, and mathematics into a problem-solving-based learning process rooted in real-life contexts (Muttaqiin, 2023; Fadillah, 2024). This approach plays a crucial role in improving the quality of physics education in high school through active, contextual, and student-centered learning.

In physics education, the implementation of STEM encourages students to engage in experimentation, investigation, and problem-solving, thereby enhancing their conceptual understanding and higher-order thinking skills (Putri et al., 2025; Hayat, 2024). This process makes learning more meaningful as students connect abstract concepts with real-world phenomena.

Furthermore, various studies indicate that integrating STEM with learning models such as Project-Based Learning and Problem-Based Learning can enhance 21st-century skills, particularly critical thinking, creativity, communication, and collaboration (Megawati et al., 2023; Lestari et al., 2025). The use of technologies such as interactive multimedia also strengthens students' digital literacy and science literacy (Widya et al., 2024).

A review of the literature also indicates that project-based learning makes a significant contribution to improving Higher-Order Thinking Skills (HOTS) and 21st-century skills, as students are trained to solve problems systematically and produce learning outcomes (Sulistyawan & Masturi, 2025). This reinforces the importance of active learning approaches in the implementation of STEM.

Trends in educational research indicate that the integration of STEM into physics instruction continues to grow and consistently demonstrates a positive impact on students' cognitive abilities and 21st-century skills (Yulianti et al., 2025). Furthermore, the reinforcement of the 6C framework also broadens the scope of skills developed through STEM, including character and citizenship (Warsito & Yasin, 2024).

Overall, the literature review reveals a strong relationship between STEM education, physics instruction, and 21st-century skills. STEM serves as a key variable influencing the learning process, which ultimately leads to the enhancement of students' 21st-century skills through active, contextual, and problem-based learning.

Thus, the conceptual framework of this study illustrates that STEM education in high school physics serves as the primary approach influencing the development

of 21st-century skills through interactive, collaborative, and problem-solving-based learning processes (Mustamiin et al., 2026; Fadillah, 2024).

RESEARCH METHODOLOGY

A. Research Design

This study employs a descriptive qualitative approach using a literature review method. The literature review method was used to examine, analyze, and synthesize various previous research findings relevant to the research topic, namely the role of STEM education in developing 21st-century skills in high school physics learning. This approach aims to provide a comprehensive overview of concepts, research findings, and patterns of relationships among variables based on published literature (Putri et al., 2025; Yulianti et al., 2025).

B. Research Subjects, Object, and Sample

The subjects of this study are scientific articles or journal publications related to STEM education, high school physics learning, and 21st-century skills. The object of this study is the analysis of 15 previously selected national journal articles. The research sample consists of 15 scientific articles selected through purposive sampling based on specific criteria, namely: (1) relevance to STEM topics and physics instruction, (2) publication within the last 5 years, and (3) origin from credible national journals or scientific proceedings.

C. Data Collection Techniques and Instruments

Data collection in this study was conducted through document analysis. Data were obtained from scientific journal articles relevant to the research topic. The research instrument used was a literature review matrix containing columns for recording key information from each article, such as: author, year, research objectives, methods, results, and conclusions.

D. Data Analysis Techniques

Data analysis was conducted using content analysis and thematic synthesis. The analysis steps included:

a. Identifying and grouping articles based on research themes.
b. Conducting an in-depth analysis of the content of each article.
c. Grouping findings based on research variables (STEM, physics learning, 21st-century skills).
d. Conducting a synthesis to identify patterns of relationships among variables.
e. Drawing conclusions based on the results of the literature analysis.

This analysis aims to provide a comprehensive understanding of the role of STEM education in developing 21st-century skills in high school physics learning.

RESULTS AND DISCUSSION

Based on the results of a study of fifteen articles that met the scientific inclusion criteria, a comprehensive description of the literature review on the role of STEM education in developing 21st-century skills in high school physics was obtained. All reviewed articles were published between 2022 and 2026, originated from various higher education institutions in Indonesia, and employed research methodologies with diverse

approaches. A summary of the study's findings is presented in Table 1 below.

Table 1: Summary of Studies on a Literature Review of the Role of STEM Education in Developing 21st-Century Skills in High School Physics (2022–2026)

No	Researcher & Year	Method	Sample/ Subject	Variables	Focus Platform	Key Findings
1	Putri et al. (2025)	Systematic Literature Review	STEM Articles 2014–2025 STEM	STEM, cognitive	Physics learning	STEM enhances cognitive abilities and higher-order thinking skills (HOTS)
2	Yulianti et al. (2025)	Systematic Review	Indonesian STEM Articles	STEM, Research Trends	Physics Education	STEM Trends Are on the Rise and Dominate PBL/PjBL
3	Megawati et al. (2023)	Literature Review	Physics Education Articles	PjBL-STEM, 4C	STEM-Based PjBL	Enhancing 21st-Century Skills
4	Maghfirah et al. (2025)	SLR	High School Physics HOTS Articles	HOTS	Physics Education	Innovative Models to Enhance HOTS
5	Lestari et al. (2025)	Literature Review	Physics PBL Articles	PBL, 4C	High School Physics	PBL Enhances Critical Thinking
6	Widya et al. (2024)	Research & Development review	Artikel multimedia	STEM, literasi digital	E-multimedia fisika	Meningkatkan literasi sains & digital
7	Sulistyawan & Masturi (2025)	Meta-analysis	Physics PjBL articles	PjBL, HOTS	Project-based learning	PjBL effectively enhances HOTS
8	Khalishah & Mahmudah (2022)	Literatur review	21st-century STEM articles	STEM, 4C	STEM education	STEM is relevant to 21st-century skills
9	Warsito & Yasin (2024)	Conceptual review	6C articles	6C skills	Digital education	STEM supports the 6C (citizenship, character)
10	Muttaqiin (2023)	Theoretical review	Science articles	STEM	Science learning	STEM develops 21st-century skills
11	Roslina et al. (2022)	SLR	STEM-PjBL articles	STEM-PjBL	Physics	PjBL-STEM effectively enhances the 4C
12	Mustamiin et al. (2026)	Literature review	Science education articles	Future competencies	Science education	STEM is relevant to future competencies

13	Rosyidah et al. (2026)	Literature review	Science literacy articles	Science & math literacy	21st-century learning	Literacy enhances HOTS
14	Hayat (2024)	Experimental research	High school students	STEM, physics concepts	High school physics learning	STEM enhances conceptual understanding
15	Fadillah (2024)	Theoretical review	STEM education articles	STEM, 21st-century skills	Science education	STEM is essential in the 21st century

A synthesis of 15 articles shows that STEM education plays a very strong role in enhancing 21st-century skills in high school physics instruction. Nearly all studies indicate that integrating STEM into instruction can improve students' critical thinking, creativity, collaboration, communication, and higher-order thinking skills (HOTS).

Key findings indicate that the most commonly used instructional models in STEM implementation are Project-Based Learning and Problem-Based Learning. This suggests that STEM does not stand alone but is integrated with active, student-centered instructional models (Megawati et al., 2023; Roslina et al., 2022).

Furthermore, the study's results indicate that STEM also contributes to improving science literacy and digital literacy through the use of technologies such as interactive e-multimedia (Widya et al., 2024). This reinforces the notion that STEM focuses not only on concepts but also on the use of technology in learning.

In terms of 21st-century skills, all studies indicate improvements in the 4C and HOTS domains. STEM-based learning encourages students to be more active in problem-solving, collaborating, and communicating their thoughts scientifically (Lestari et al., 2025; Sulistyawan & Masturi, 2025).

Furthermore, the literature review also indicates that STEM is highly relevant to the development of future competencies, including the 6C skills, which encompass character and citizenship (Warsito & Yasin, 2024). This suggests that STEM not only develops students' cognitive aspects but also their affective and social aspects.

Overall, the results of this synthesis consistently show that STEM education is an effective approach for enhancing 21st-century skills in high school physics learning. The integration of STEM with active learning models and technology is a key factor in the successful development of students' competencies.

CONCLUSION

Based on the synthesis of the 15 articles analyzed, it can be concluded that STEM education plays a significant role in enhancing 21st-century skills in high school physics education. The integration of STEM into learning—particularly when combined with Project-Based Learning (PjBL), Problem-Based Learning (PBL), and the use of technology-based media—has been shown to enhance students' critical thinking, creativity, communication, collaboration, and Higher-Order Thinking Skills (HOTS). Furthermore, STEM also contributes to improving science literacy and digital literacy through contextual and problem-solving-based learning. Overall, STEM education has proven effective in holistically developing 21st-century skills, making it highly relevant for implementation in high school physics education.

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