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Application of STEM in Educational Curricula: a Literature Review

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ABSTRACT

This study aims to examine the implementation of the Science, Technology, Engineering, and Mathematics (STEM) approach in educational curricula through a systematic literature review (SLR) method using the PRISMA framework. The main focus of this research is to evaluate how the STEM approach is integrated into various educational levels, identify implementation challenges, and assess its impact on the development of 21st-century skills such as critical thinking, creativity, communication, and collaboration (4C). Data were obtained from 239 scholarly articles accessed through databases such as Google Scholar, Scopus, SINTA, GARUDA, Crossref, and ICI. After a rigorous selection process based on inclusion criteria, 25 articles were chosen for further analysis. The results of the study indicate that consistent STEM implementation can enhance student motivation, interdisciplinary concept understanding, and problem-solving skills. However, several barriers were also identified, such as a lack of teacher training, limited resources, and low educational policy support. Therefore, this study provides valuable contributions to formulating recommendations for the development of more effective STEM-based educational policies in the future.

INTRODUCTION

Entering the 21st century, the world of education faces increasingly complex and dynamic challenges. Rapid technological developments and globalization demand changes in the education system to produce graduates who not only have academic knowledge but also master critical thinking, creative, collaborative, and communicative skills (4C). These skills are crucial for facing a rapidly changing job market that requires individuals who are adaptive and able to solve problems innovatively.

In line with digital transformation, education is also required to integrate science and technology comprehensively in the learning process. One approach that has rapidly developed to address this need is the STEM (Science, Technology, Engineering, and Mathematics) approach. This approach emphasizes the integration of disciplines holistically, so that students not only understand concepts theoretically but can also apply them in real-life contexts.

The learning paradigm has also undergone a significant shift. Whereas previously learning focused more on memorization and mastery of textual material, it has now shifted towards project-based learning and problem-based learning approaches.

Integrating the STEM approach into the curriculum has become an urgent need to shape a generation of independent, innovative learners who can compete globally.

Globally, some developed countries like the United States, South Korea, and Finland have successfully implemented STEM-based education with strong policy support, ongoing teacher training, and collaboration between educational institutions and industries. In Indonesia, efforts to implement STEM have started, particularly through the Merdeka Belajar program and strengthening the Merdeka curriculum. However, the challenges faced are quite diverse, ranging from the lack of training for educators, limited infrastructure and resources, to the unpreparedness of the curriculum at the educational unit level. Additionally, there is still a gap between concept and practice on the ground. Many teachers are not yet familiar with interdisciplinary approaches and continue to use conventional methods in teaching science, mathematics, and technology. This requires adjustments in the curriculum and strengthening teacher competencies so that STEM implementation can be truly optimal and aligned with the needs of the times.

Given these dynamics, it is important to conduct a literature review to evaluate the effectiveness of STEM education implementation from various studies that have been conducted. This literature review aims to map trends, challenges, and best practices in STEM implementation, while also providing a foundation for formulating strategies for developing more relevant and sustainable educational policies. Thus, education in Indonesia can progress and produce superior human resources in the fields of science and technology.

This study aims to examine the application of STEM (Science, Technology, Engineering, and Mathematics) in educational curricula, with a focus on its effectiveness in improving the quality of learning in schools. Specifically, this research aims to identify the challenges faced in implementing STEM in Indonesia, both at the primary and secondary education levels. Furthermore, this study also seeks to explore best practices in STEM implementation that have been successfully applied in developed countries, as well as analyze the factors influencing the success and barriers in integrating STEM into the curriculum. Through this research, it is hoped that recommendations can be found for the development of education policies in Indonesia, as well as effective strategies to enhance teacher capacity and provide infrastructure that supports STEM-based learning.

METHODOLOGY

This study uses a qualitative approach with a literature review method, aimed at examining and analyzing various literatures related to the implementation of the STEM (Science, Technology, Engineering, and Mathematics) approach in educational curricula. The literature review allows the researcher to explore various previous studies that are relevant and to construct a comprehensive understanding of this topic. In this case, the focus of the study is to evaluate the effectiveness of STEM implementation, the challenges faced, and the best practices that can be applied in the context of education in Indonesia.

The primary data sources for this research are obtained through a literature review that includes scholarly articles, research journals, books, and policy reports related to the implementation of STEM in education across different countries. Additionally, the study will review case studies from countries that have successfully implemented STEM-based education at various levels, from primary education to higher education. Thus, this literature review provides a broad overview of STEM implementation in various global education systems.

The criteria for selecting literature are based on the relevance and quality of the sources. The literature used is primarily selected from publications published within the last five years, ensuring that the information used in this study is up-to-date and relevant to the latest developments in the field of STEM education. Moreover, the selected literature also covers various aspects related to STEM, ranging from the basic theory of STEM, models of STEM curriculum implementation in different countries, challenges faced by educators in implementing STEM, to the evaluation results and impacts of STEM implementation on student learning quality.

The literature collection process involves searching for sources from various academic databases, such as Google Scholar, JSTOR, and ProQuest, which provide scholarly articles and journals related to STEM. Literature selection is carried out by filtering the most relevant sources based on criteria such as publication year, research topic, and journal or publisher quality. This aims to obtain accurate and verified data to support the analysis that will be conducted.

After the literature is collected, qualitative synthesis is used to analyze and organize information from various sources. The collected data will be analyzed using thematic coding to identify the main themes related to STEM implementation in education. These themes include challenges in STEM implementation, successful applications, educational policies supporting STEM, and the impact of STEM implementation on student learning outcomes. This thematic analysis allows the researcher to identify patterns that can provide new insights for the development of education policies in Indonesia.

The systematic discussion in this study will be organized thematically, covering important topics such as the history of STEM development, examples of STEM implementation in developed countries, and the barriers faced in implementing STEM in Indonesia. This study will also discuss recommendations from previous research on strategies that can be used to overcome challenges in STEM implementation, both at the policy level and in practical field applications.

The main goal of this analysis is to draw conclusions on the key trends in STEM implementation and its impact on the quality of learning. This research also aims to identify the main challenges faced by educators in implementing STEM and provide practical recommendations to address these obstacles, thereby improving the quality of STEM education in Indonesia.

The inclusion criteria table outlines that the selected articles must be published in reputable international or national journals within the last six years (2018–2024), and indexed in well-established databases such as Google Scholar, SINTA 1–6, Scopus Q1–NonQ, GARUDA, Crossref, and ICI. The articles should be written in either English or Indonesian to allow for a broader yet relevant scope of literature. This review focuses on studies related to the implementation of STEM (Science, Technology, Engineering, and Mathematics) in educational curricula, examining aspects such as student engagement, development of 21st-century competencies (4C: Critical thinking, Creativity, Collaboration, and Communication), changes in teaching methods, technological integration, and challenges of implementation. The field of study includes Education and STEM-related disciplines, and incorporates both theoretical and empirical research. Keywords used in the search include “STEM Education,” “Curriculum Implementation,” “STEM and 21st Century Skills,” and “STEM Learning Innovation.” This structured inclusion process ensures that the review presents a comprehensive and credible analysis

of how STEM is being applied in education, its effectiveness, and areas for further development.

Table 1. Inclusion criteria for literary research

Category	Inclusion Criteria
Publication Type	Scientific articles published and accessible via Google Scholar
Journal Specifications	Top international journals and accredited national journals published within the last 6 years (2018–2024)
Journal Index	Indexed in Google Scholar, SINTA (1–6), Scopus (Q1–Non-Q), GARUDA, Crossref, and Index Copernicus International (ICI)
Publication Year	2018–2024
Country of Research	Studies conducted in Indonesia and other countries
Variable	Implementation of STEM-based learning, student interest and acceptance of STEM, its influence on 21st-century skills, and challenges and strategies in STEM education
Field of Study	Education, Science, Technology, Engineering, and Mathematics
Type of Study	Theoretical and empirical research
Keywords	STEM Education, Implementation of STEM, 21st Century Education, Curriculum Development, Learning Innovation, 4C Skills (in English and Bahasa Indonesia)
Subjects	Research involving students, teachers, educators, and educational institutions engaged in or examining STEM-based curriculum

The inclusion criteria table emphasizes that the selected articles must be published in top international and national journals within the last six years (2018–2024) and indexed in reputable databases such as Google Scholar, SINTA 1–6, Scopus Q1–NonQ, GARUDA, Crossref, and ICI. Articles are required to be written in either English or Indonesian to ensure a wide yet focused range of academic literature. The studies must explore the implementation of STEM-based learning in education, particularly its impact on student interest, development of 21st-century skills, curriculum innovation, and teaching strategies. Relevant fields include Education, Science, Technology, Engineering, and Mathematics, with an emphasis on both theoretical and empirical studies. Key topics and keywords used in the literature search include “STEM Education,” “Implementation of STEM,” “21st Century Skills,” “Curriculum Development,” and “Learning Innovation” in both English and Bahasa Indonesia. This rigorous selection process aims to provide a comprehensive and high-quality review of the implementation of STEM in education, ensuring that only the most relevant and impactful studies are included in the analysis.

RESULTS AND DISCUSSION

Literature Search Results

Through a comprehensive literature review utilizing the Systematic Literature Review (SLR) method guided by the PRISMA framework, a total of 239 articles were retrieved from various databases such as Google Scholar, Scopus, SINTA, GARUDA, Crossref, and ICI. After applying strict inclusion and exclusion criteria, only 25 articles met the requirements for in-depth analysis. These selected studies, published between 2018 and 2024, represent diverse perspectives from multiple countries, including Indonesia, and focus on the integration and implementation of STEM (Science, Technology,

Engineering, and Mathematics) in educational curricula.
The analysis reveals the following findings:

1. Structured and consistently applied STEM-based learning models are significantly more effective in improving students' understanding and interest in science and technology.
2. The success of STEM implementation in schools is influenced by several key factors, including the availability of adequate teaching resources, teacher competence in interdisciplinary approaches, institutional support, and the incorporation of 21st-century skills into learning objectives.

This review includes a wide range of studies that passed initial screening and follow-up assessments. The final 25 articles reflect varied origins, publication years, and educational contexts. The selected studies employed diverse research methods, including quantitative, qualitative, and mixed approaches. Despite variations in origin and methodology, the results provide a comprehensive insight into the key elements, challenges, and best practices in implementing STEM within education systems.

Study Selection Flowchart

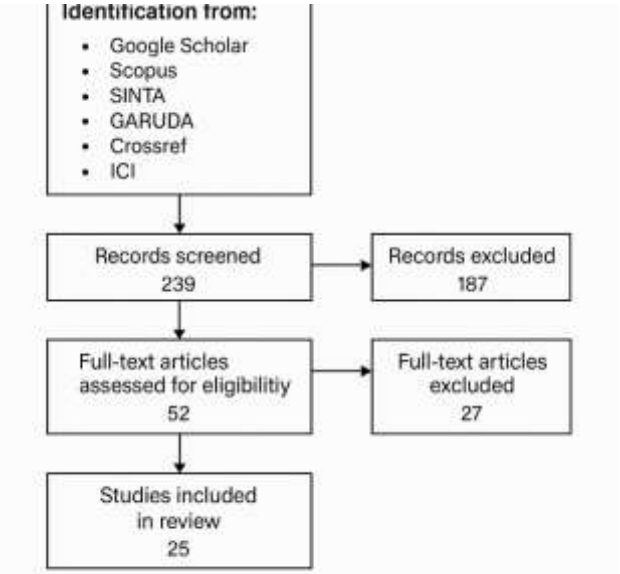

Figure 1. Flowchart of Study Selection

Figure 1 shows the selection flow of studies using the Systematic Literature Review (SLR) method, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. From a total of 239 articles identified through various databases such as Google Scholar, Scopus, SINTA, GARUDA, Crossref, and ICI, an initial screening process was conducted to remove duplicates and select articles based on their titles and abstracts. After that, a full-text evaluation of the remaining articles was carried out, resulting in 25 articles that met the inclusion criteria and were suitable for in-depth analysis. This process demonstrates a systematic stage in ensuring that only relevant, high-quality studies related to the topic "Application of STEM in the Education Curriculum" are analyzed in this literature review.

Students' Acceptance and Interest in STEM

The application of STEM in the curriculum has shown a significant impact on students' interest and enthusiasm for learning. Students engaged in STEM-based learning tend to be more interested and feel the relevance of the material being taught to their daily lives. Factors influencing students' interest include hands-on learning experiences, involvement

in practical projects, and the use of technology in learning. Students who have the opportunity to work in groups and solve real-world problems show higher interest in Science, Technology, Engineering, and Mathematics (STEM) fields. Furthermore, interest differences are also seen based on gender, age, and educational background, with some student groups being more inclined towards certain fields such as engineering or technology.

Enhancement of 4C Skills (Critical Thinking, Creativity, Collaboration, Communication)

The application of STEM plays a vital role in developing 4C skills that are highly needed in the modern workforce. Students involved in project-based and experimental learning become more skilled in critical thinking, creatively solving problems, working in teams, and communicating effectively. They are trained not only to find solutions but also to develop innovative ideas and present them clearly. Before STEM application, students often focused more on theory and memorization, but afterwards, they can apply knowledge to solve real problems. This change shows significant development in students' ability to work collaboratively and think analytically.

Impact of STEM on Students' Academic Performance

Research shows that the application of STEM can improve students' academic performance, especially in subjects related to science, technology, and mathematics. Students involved in STEM-based learning are more active in the learning process, leading to better understanding of the material. Some studies also note that there are significant differences in exam and assignment results involving STEM concepts compared to traditional learning methods. Moreover, students with a high level of involvement in STEM learning tend to perform better, not only in STEM subjects but also in analytical skills and problem-solving abilities.

Changes in Teaching and Learning Methods

The application of STEM in the curriculum has brought changes in teaching methods used by teachers. From traditional methods focused on lectures, STEM-based teaching involves more experiments, group projects, and the use of technology to enhance students' understanding. Teachers, who were previously accustomed to conventional approaches, are now required to be more creative in designing interactive and applied learning. However, there are challenges in terms of teachers' readiness and acceptance of these changes. Some teachers may need additional training or more time to master new techniques required in STEM education. Moreover, existing curricula sometimes do not fully support the project-based approach expected in STEM learning.

Challenges in STEM Implementation in Indonesia

The implementation of STEM in Indonesia still faces several challenges. One of the main obstacles is the lack of adequate facilities in many schools, especially in remote areas. Many schools do not have science laboratories or the technological tools needed to support STEM-based learning. Additionally, teacher training is also an important issue, as many teachers have not received sufficient training to teach STEM concepts effectively. Budget constraints in education often hinder the procurement of necessary resources for STEM implementation. External factors such as education policies that are less focused on STEM and public perceptions that lack depth regarding the importance of STEM education also affect the success of STEM implementation in Indonesia.

The Role of Technology in STEM Learning

Technology plays a key role in enriching STEM learning. The use of educational software, interactive applications, and virtual laboratories provides students with the

opportunity to delve deeper into STEM concepts in a more engaging and practical manner. Technology allows students to access information more quickly and conduct virtual experiments that might be difficult to carry out in physical laboratories. However, challenges related to technology use include limited access to adequate devices, especially in underdeveloped areas. Dependence on specific technologies can also be problematic if those devices are not available evenly across all schools.

Industry Involvement in STEM Education

Industry involvement in STEM education in Indonesia is still relatively limited, although some partnerships between schools and industries have been made. Internship programs, industry visits, or donations of technological devices from companies can help improve the quality of STEM education. Collaboration between the education sector and industry can also help bridge the gap between the skills students have and those required by the labor market. If the industry sector becomes more active in the development of STEM curricula and teacher training, it will further strengthen the quality of STEM education in Indonesia.

Evaluation of the Impact of STEM Implementation on Work and Job Readiness

STEM learning has a significant impact on students' preparedness to enter the workforce, especially in sectors that require technical and analytical skills. Students involved in STEM learning tend to have higher critical thinking, problem-solving, and creativity skills, which are highly valued by many companies in the labor market. With these skills, they are better prepared to adapt to technological advancements and the ever-changing labor market demands. STEM implementation in schools can also help reduce the gap between the skills required by the industry and the competencies possessed by school graduates.

Recommendations for Improving STEM Implementation

Based on this study's findings, several recommendations can help improve STEM implementation in Indonesia. One of them is improving school facilities and infrastructure, including providing adequate laboratories and technological devices that can support STEM-based learning. Continuous teacher training is also key to improving STEM teaching quality. Furthermore, curriculum updates that are more integrated with technological developments and industry needs will help strengthen STEM implementation across educational levels in Indonesia.

Overall, this study shows that the application of STEM has a positive impact on students' interest, 4C skills, and academic performance. However, challenges such as limited facilities and teacher training need to be addressed for effective STEM implementation. Therefore, it is important to continue strengthening collaboration between the education sector, government, and industry to create an education system that is more adaptive and ready to face global developments.

STEM as a Solution to 21st Century Challenges

The application of STEM (Science, Technology, Engineering, and Mathematics) is considered one of the key solutions to address the challenges of 21st-century education, particularly in developing essential skills that are highly needed in today's professional world, such as critical thinking, creativity, collaboration, and communication, commonly referred to as 4C. These skills are crucial, considering the digital era and industrial revolution driving rapid changes in the workforce. Through STEM-based learning, students are trained not only to understand theory but also to apply it in real-world situations through problem-solving and projects. This learning prepares students to adapt to constantly evolving technology and provides them with expertise that can be used

across various industry sectors, such as information technology, engineering, and science, all of which play a significant role in advancing the global economy.

Global Trends in STEM Implementation

Globally, the implementation of STEM has had a significant impact on enhancing 21st-century skills in students. Developed countries such as the United States, Singapore, and Canada have successfully integrated STEM into their curricula with a focus on project-based learning and problem-solving. For example, in Singapore, STEM has become an integral part of the curriculum from primary to secondary education, aimed at increasing students' interest in science and technology. This success was achieved thanks to well-developed curricula, strong government support, and sufficient facilities for STEM-based learning. However, these countries also face several challenges, such as dealing with fragmented curricula and limited facilities that support broader STEM education.

STEM Implementation in Indonesia

In Indonesia, STEM implementation is still in its early stages and is limited to certain schools or educational institutions. This implementation is not yet widespread, both in terms of curriculum and supporting infrastructure. Although there have been some initiatives to adopt STEM approaches, such as certain schools beginning to introduce STEM-based projects, a major challenge is the lack of teacher training and limited facilities that support hands-on learning in these fields. The government needs to develop more targeted policies to expand STEM implementation across Indonesia, including creating a more adaptive curriculum and enhancing teacher training quality.

Barriers to STEM Implementation in Indonesia

Several major barriers to STEM implementation in Indonesia include inadequate teacher training in teaching STEM concepts, limited facilities and resources, and budget constraints allocated for STEM education development. Many schools, especially in remote areas, lack adequate facilities such as complete science laboratories, technology devices, or even simple teaching aids to support STEM learning. Furthermore, budget limitations in education also hinder the procurement of teaching materials and the development of relevant curricula. This needs to be a priority for the government to address disparities and accelerate the adoption of STEM across Indonesia.

Successes and Best Practices in STEM Implementation

Successes in STEM implementation can be found in countries like Finland and South Korea, which have developed project-based and interdisciplinary approaches in STEM education. One successful example is Finland, which integrates STEM into the curriculum holistically, with a focus on problem-solving and collaboration among students. This success is driven by collaboration between the government, schools, and industry to create an environment that supports high-quality STEM education. In Indonesia, adopting best practices from these countries can be done by strengthening the relationship between the education sector and industry, ensuring that the developed curriculum aligns with the needs of the labor market.

Impact of STEM Implementation on Learning Outcomes

STEM implementation has proven to have a positive impact on students' learning outcomes, particularly in the development of critical thinking skills and problem-solving abilities. Students engaged in STEM learning tend to be more skilled at identifying problems and designing creative solutions, which are highly sought after in the workforce. Moreover, STEM education also encourages students to work in teams, improving their collaboration and communication skills. This is highly relevant to the demands of the job

market, which now prioritizes interpersonal skills and the ability to work in fast-paced, multidisciplinary environments.

Recommendations for STEM Development in Indonesia

To accelerate STEM development in Indonesia, a more flexible and relevant curriculum update is needed. This update should include the integration of STEM concepts across various subjects and the strengthening of project-based learning that links theory with practice. Additionally, it is crucial to enhance teacher training, both through direct and online training, to ensure they can teach STEM effectively. Strengthening cooperation between the education sector and industry is also essential to provide adequate facilities and ensure that the education provided meets the needs of the job market.

The Role of Educational Policies in Supporting STEM

Educational policies that support STEM integration are crucial in accelerating STEM adoption across all levels of education in Indonesia. The government needs to provide sufficient funding, high-quality teacher training, and adequate facilities to support STEM implementation. Additionally, better coordination between central and local governments will help address disparities in providing necessary facilities and training. Well-coordinated policies can ensure that all schools, both in urban and remote areas, have equal access to STEM education.

Implications for Educational Policy Development and Practical Recommendations

The findings of this study suggest that STEM implementation has great potential to improve the quality of education in Indonesia, but this requires comprehensive policy support and well-planned implementation. The government and other stakeholders must work together

CONCLUSION

Based on the research findings, it can be concluded that the implementation of STEM education in Indonesia has a significant impact on increasing student interest, the development of 21st-century skills, and academic achievement. Students show high enthusiasm for STEM-based learning, especially when the material presented is relevant, applicable, and linked to real-life experiences as well as project-based activities. Furthermore, the STEM approach has proven to enhance students' 4C skills (Critical Thinking, Creativity, Collaboration, Communication) holistically. This is reflected in students' ability to solve problems, collaborate in teams, and effectively communicate ideas. The study also shows that the implementation of STEM can improve academic performance, particularly in science, mathematics, and technology subjects. However, there are several challenges to be faced, including limited infrastructure, insufficient teacher training, and suboptimal support from educational policies. Nevertheless, the use of technology and industry involvement has made a positive contribution to supporting the success of the STEM program. Therefore, to improve the quality of STEM implementation in the future, a strong synergy between the government, schools, the industry, and society is required. The government needs to provide supporting policies, such as continuous teacher training, the development of adaptive curricula, and the provision of adequate facilities. This research highlights the importance of transforming Indonesia's education system to produce a generation that is ready to compete in the global era and Industry 4.0.

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