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A Systematic Review of STEM Education Implementation in Indonesian High Schools: Opportunities, Challenges, and Policy Recommendations

Necta Ayu Cahyanti[1,*], Slamet Suyanto[1], Ngade Wantara[1], Guldana A. Begimbetova[2], Habibatul Unayah[1], & Muhammad Rasyid[3]

[1]Departement of Biologi Education, Yogyakarta State University, Indonesia

[2]Abai Kazakh National Pedagogical University, Almaty, Kazakhstan

[3]Departement of Biologi Education, Yogyakarta State University, Indonesia

Abstract: The purpose of this study is to analyze the implementation of the STEM approach (Science, Technology, Engineering, and Mathematics) in Indonesia, particularly in high schools, through a systematic literature review. STEM is recognized as an innovative learning method that integrates various disciplines to enhance 21st-century skills, such as critical thinking, problem-solving, and student creativity. The analysis reveals that the implementation of STEM positively impacts student outcomes, interest, and motivation, especially in project-based and technology-driven learning. However, several challenges persist, including limited facilities, insufficient teacher training, and unequal access to technology in certain regions. To ensure the sustainability of STEM implementation, strategies should include the development of a flexible curriculum, intensive training for teachers, and collaboration with industry and private sectors. This study underscores that, with proper management, STEM-based learning holds significant potential to improve the quality of education in Indonesia, particularly at the high school level, and to prepare students for the challenges of the modern era. The findings of this study are expected to serve as a reference for designing more innovative and inclusive educational policies and practices.

Keywords: implementation, STEM, high school, indonesia, literature review.

▪ INTRODUCTION

The rapid development of science and technology demands significant changes in the education system, particularly at the high school level, to prepare students for a dynamic and technology-driven workforce. One innovative approach that supports the development of 21st-century skills is STEM education (Science, Technology, Engineering, and Mathematics). This approach integrates various disciplines to help students develop critical thinking, problem-solving, collaboration, and communication skills. Through project-based and contextual learning methods, students can connect theoretical knowledge with real-world applications, thereby increasing interest in science and technology while equipping them with technical and soft skills such as creativity and adaptability. A well-structured STEM education program aims not only to improve learning outcomes but also to prepare students to become competent individuals ready to face global challenges (Stehle & Peters-Burton, 2019).

STEM (Science, Technology, Engineering, and Mathematics) is an educational approach that integrates four core disciplines—science, technology, engineering, and mathematics—into a holistic learning framework (Suryanti, 2021). The primary goal of STEM education is to develop essential 21st-century skills, such as critical thinking, problem-solving, collaboration, and adaptability in an ever-changing world. The STEM approach provides students with opportunities to learn through practical and applied experiences, preparing them to contribute to rapidly advancing technology, industry, and scientific sectors (Davidi et al., 2021).

Necta Ayu Cahyanti
*Email: nectaayu.2024@student.uny.ac.id

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STEM learning does not merely focus on mastering scientific content but also emphasizes applying this knowledge to real-world situations. This concept highlights interdisciplinary integration, enabling students to understand how classroom theories can be applied to address societal or industrial challenges (Fadillah, 2024). Project-based learning is often employed to encourage students to design real-world solutions using knowledge from science, technology, engineering, and mathematics. The concept of STEM at the high school level refers to an integrated interdisciplinary approach, uniting science, technology, engineering, and mathematics. (Suryanti, 2021) This concept aims to integrate the four disciplines into a holistic learning process, allowing students to understand the interrelationships among scientific fields and apply them in real-world situations (Fauzi et al., 2023).

The STEM approach enables students to develop critical thinking, creative thinking, and collaborative skills while preparing them for future challenges (Davidi et al., 2021). STEM education offers numerous benefits, including enhancing students' critical and analytical thinking abilities. According to research by Capraro et al. (2013), STEM education also encourages students to innovate and think creatively, as they are often faced with real-world challenges requiring new and effective solutions. Furthermore, Rowland and Harker (2016) emphasized that STEM-based learning helps students better understand how technology can transform their professional interactions and work (Agustin, 2023).

The relevance of STEM in the context of high school education is crucial, as it prepares students for an era of technology and innovation. By integrating Science, Technology, Engineering, and Mathematics, students can develop critical, innovative, and creative thinking skills needed in the workforce (Kusnadi et al., 2024). The implementation of the STEM approach in high schools also plays a role in increasing students' interest in science and technology. Through relevant, engaging, and applicable learning, students become more interested and enthusiastic about exploring science and technology concepts (TOBING & SULASTRI, 2024). This shift can help transform students' perceptions of science and technology subjects, which are often considered difficult and boring, into something intriguing and worthwhile to explore further (Mu’minah, 2021). Moreover, the STEM approach promotes cross-disciplinary collaboration and the application of contextual learning concepts. This aligns with the objectives of high school education, which aims to equip students with skills they can apply in real life (Lestari, 2021).

Despite its many benefits, the implementation of STEM in high schools still faces several challenges. One major issue is the lack of resources, including facilities, materials, and teacher training. Zhang and Wang (2018) noted that many schools lack adequate equipment and technological tools to support effective STEM learning. Additionally, not all teachers possess the skills or training necessary to integrate STEM into their teaching practices (Bybee, 2013). Research shows that STEM education is still not fully integrated into national curricula in many countries, making it difficult to implement this method consistently and widely (Rowland & Harker, 2016). This can lead to a mismatch between STEM education goals and field practices. Therefore, it is important to understand how STEM implementation models have been applied, the challenges faced, and the best practices that can be adopted in various educational contexts.

This systematic literature review aims to examine various studies on STEM learning implementation in Indonesia, particularly in high schools, which to date has rarely been a focus of in-depth research. This study addresses previous research gaps by giving special attention to Indonesia's local context, such as unique challenges related to access to technology, educational resources, and regional disparities. Moreover, the study identifies the benefits of STEM implementation in high schools, key factors influencing its success, and barriers to implementation in greater detail, including aspects of policy, teacher training, and technological integration in learning. Through this approach, the study offers recommendations that are not only conceptual but also practical, such as developing a curriculum based on local context and conducting teacher training aligned with field needs. Thus, this research provides a significant contribution to supporting the broader, more effective, and more relevant implementation of STEM in high schools across Indonesia.

Research Questions:

1. What are the benefits of implementing the STEM approach in Indonesian high schools education?
2. What are the supporting and inhibiting factors for implementing the STEM approach in Indonesian high schools?
3. What are the recomended effective strategies for implementing the STEM approach in Indonesian high schools?

▪ METHOD

Research Design

This study uses a Systematic Literature Review (SLR) design, which is a structured and systematic method for identifying, evaluating, and synthesizing findings from previously published research. This design was chosen because it provides a deeper and more comprehensive understanding of the implementation of STEM education in high schools. By employing this approach, the study aims to gather evidence from various verified sources to offer a more holistic and objective view of the challenges, strategies, and factors influencing the success of STEM implementation. This process ensures that the results are representative and based on valid, relevant data, specifically tailored to the context of high school education in Indonesia, while considering multiple perspectives to enrich the understanding of this topic.

Search Strategy

The literature search was conducted through electronic searches in internationally recognized academic databases, such as Google Scholar, SpringerLink, and Scopus, which are known to provide high-quality, peer-reviewed, indexed articles. Additionally, the Publish or Perish software was used to optimize the search process by providing citation analysis metrics for each article found. Keywords used in the search included: "STEM education in high schools," "implementation of STEM," "STEM curriculum," "challenges in STEM education," and "strategies for STEM teaching," along with relevant variations aligned with the focus of the research. This strategy was designed to reach publications across various relevant disciplines, covering both international and local studies, to ensure a diversity of perspectives in the discussion of STEM implementation. Each article found will be filtered to ensure its relevance to the research focus, and only those meeting the inclusion criteria will proceed to further evaluation.

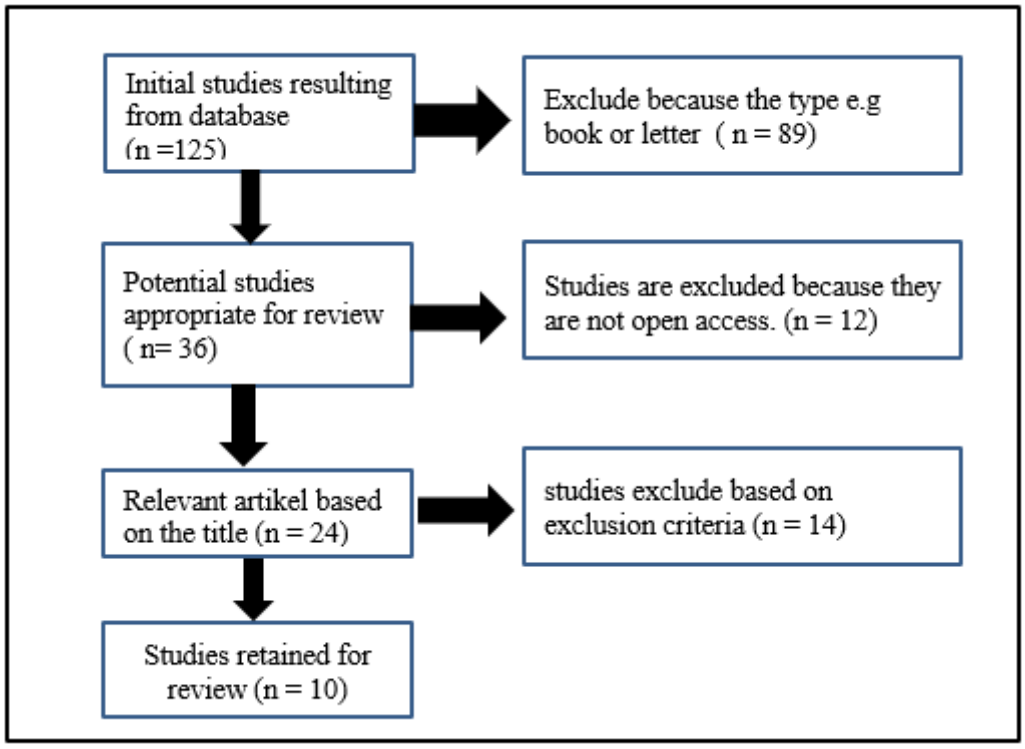

Figure 1. Article selection used in SLR using PRISMA model

Article Selection Process

The article selection process is carried out in two stages: (a) First stage: Screening articles based on the title and abstract to ensure that the article discusses the implementation of STEM in high schools. (b) Second stage: Full reading of the articles to verify relevance and research quality. Studies that meet the criteria will proceed to the data extraction stage. The data to be extracted includes information related to: research objectives, methodologies used, findings related to STEM implementation, challenges faced, and strategies recommended in the study.

Eligibility Criteria

This study screens literature relevant to the implementation of STEM education in high schools, focusing on aspects of challenges, strategies, and success factors. Studies that meet the eligibility criteria must provide in-depth insights into the application of STEM in the educational context, particularly in Indonesia, and use clear methodologies and valid data.

Inclusion Criteria

- Studies that discuss the implementation of STEM at the high school level, both in local Indonesian and international contexts.
- Studies that use a clear and systematic research design, such as experiments, case studies, surveys, or interviews.
- Articles published in indexed scientific journals or conferences with peer review.
- Studies published in the last 15 years to ensure relevance to current educational conditions.

- Articles available in languages accessible to the researcher, with a preference for English or Indonesian.

Exclusion Criteria

- Studies that do not focus on the implementation of STEM in high schools or are not relevant to the discussed topic.
- Studies that lack sufficient empirical data or are merely opinions without clear analysis.
- Articles published in sources without peer review or those that cannot be accessed openly and legally.
- Studies using non-standardized methodologies or of questionable quality.

Data Analysis

The data obtained from the articles that meet the inclusion criteria will be analyzed qualitatively. The analysis process involves identifying key themes related to the implementation of STEM in high schools, such as challenges faced, successes achieved, and strategies recommended. The findings will be grouped into relevant categories, such as educational policies, teacher training, and technology use. This analysis aims to provide a comprehensive overview of the factors affecting the effectiveness of STEM implementation in high schools and offer practical recommendations for future improvements.

▪ RESULT AND DISSCUSSION

This section presents the main findings obtained from the systematic review of STEM education implementation in Indonesia, specifically in high schools. The research results are organized based on key themes identified during the analysis process. This discussion aims to interpret the findings in the context of existing literature, explain the connections between the studies analyzed, and offer new perspectives that can contribute to the development of STEM education at the secondary education level. Therefore, this section not only reports the findings but also places them within a broader framework to provide insights and recommendations that can be applied.

Table 1. Implementation STEM in Indonesian high schools

Author	Artikel Title, (Year)	Subject	Result
Dara Maylisa Putri, Lini Mulyani, Misrayatul Husna	Implementation of STEM (Science, Technology, Engineering, and Mathematics) Approach in Improving Students' Learning Outcomes and Scientific Attitudes in Biology Learning (2023)	Biology	The results of the analysis of the STEM approach in biology learning show a relevant influence on student learning outcomes, especially in Biology learning. This is because the application of the STEM approach will require students to be active and able to work together with teams in their groups. High student interest and motivation in learning will be able to improve students'

			learning outcomes and scientific attitudes.
Laila Puspita, Nur Hidayah, Neneng Puspitasari, Komarudin.	The Effect of STEM-Fishbone diagram Learning on Critical Thinking Ability and Self-Efficacy: A Study on High School Students (2022)	Biology	The implementation of STEM fishbone diagram learning that was carried out provided results showing the influence of STEM-fishbone diagram learning on critical thinking skills and self-efficacy of high school students in Bandar Lampung, with suggestions that the implementation of learning activities must be able to carry out good time management so that learning can be carried out optimally.
Suji Ardianti, Fahmi Yahya, Syarif Fitrianto	The Impact of Using the STEM Education Approach with Blended Learning to Increase Students' Learning Interest (2020)	Physics	The blended learning strategy using the STEM education approach which has been implemented using the learning management system in the form of Schoology is significant in increasing the learning interest of secondary school students..
Eva Wahyuni	Efforts to improve student learning outcomes through the STEM approach in learning the concept of voltaic cells (study in class XII of SMA Negeri 2 Takengon). (2022)	Chemistry	The application of el volta learning using STEM approach steps has been proven to improve student learning outcomes in the Volta Cell material in class XII.MIPA at SMA Negeri 2 Takengon in the 2022/2023 Academic Year. This is evidenced by an increase in learning outcomes in cycle 1 to cycle 2.
Almas Zati Hulwani, Heni Pujiastuti, Isna Rafianti.	Development of Interactive Android Mathematics Learning Media with a STEM Approach to Trigonometry Material.(2021)	Mathematics	This development produces interactive android mathematics learning media with a STEM approach to trigonometry material that is valid, practical and has a potential effect on student responses in mathematics learning activities.
Ida Lydiati	Improving Student Creativity in Statistics Material Through the PjBL-STEM Learning Model for Class XII	Mathematics	This classroom action assessment shows that to improve students' creativity in Statistics material through the PjBL-STEM learning model can

	MIPA 6 SMA Negeri 7 Yogyakarta (2019)		be done by: (a) reflection, (b) research, (c) discovery, (d) application, (e) presentation. Students are trained to think and produce creative ideas through reasoning, making associations, and re-expressing what students have known and then used in solving problems.
Pramita Wally, Muhammad Tarmizi Kubangun.	Application of STEM-Based Blended Learning To The Cognitive Abilities of 11 Ambon State Senior High School Students (2023)	Biology	STEM application using blended learning model with STEM approach has an influence on increasing science literacy and cognitive abilities of grade XII students of SMA Negeri 11 Ambon in the new normal era. STEM-based blended learning model can guide and train students to think logically, critically, evaluatively, creatively in solving problems and making decisions related to dealing with life problems by utilizing technology and applying it in real life..
Jeni Pratika Surya, Abdurrahman, Ismu Wahyudi	Implementation of The STEM Learning to Improve The Creative Thinking Skills of High School Student In The Newton Law of Gravity Material	Physics	Learning with the STEM approach can significantly improve students' creative thinking skills. In using the implementation of the STEM approach to improve students' creative thinking skills, it is necessary to hold special learning activities, for example providing lots of exercises that help students become proficient in drawing conclusions that can be done at the end of learning.
Kusnadi, Nuril Huda, Muhammad Furqon, Hersiyati Palayukan, Evy Lalan Langi	Workshop on the application of STEM (science, technology, engineering, and mathematics) in secondary schools. (2024)	General subjects in STEM	The implementation of STEM through workshops conducted in high schools obtained survey results, there was a significant increase in students' interest, understanding, and confidence in learning STEM. Interactive methods that combine presentations, discussions, and practical activities have proven effective in actively engaging

			students and helping them see the relevance of STEM in everyday life.
Leni Fauziah, Lisbet Ariati Rumahorbo, Agustina Aritonang, Rosliana Siregar	Improving Computational Thinking Skills of SMA N 2 Medan Students Through the STEM Approach (2024)	Mathematics	Students' thinking skills through learning using the STEM-PBL approach with students using the innovative K13 approach show significant differences. This difference is evidence of the effectiveness of the STEM approach in improving high school students' critical thinking skills.

The implementation of the STEM (Science, Technology, Engineering, and Mathematics) approach in education can vary significantly, depending on the chosen teaching model, the subjects integrated, and the aspects measured in the evaluation. Generally, two main teaching models are commonly used: Project-Based Learning (PBL) and Problem-Based Learning (PBL). While these two models have different approaches, they both emphasize the development of similar skills (Thomas, 2000). The subjects applied within the STEM context also vary. Some approaches may focus more on teaching science and mathematics separately, with the aim of deepening students' conceptual understanding in those fields. On the other hand, an interdisciplinary approach that integrates multiple disciplines allows students to see the connections between subjects and apply them in real-world contexts. Despite variations in the focus of these subjects, all approaches aim to enhance students' technical and problem-solving skills relevant to the current technological developments (Beers, 2011).

The aspects measured in STEM implementation are also diverse, ranging from improvements in cognitive learning outcomes, the development of critical thinking skills, to creativity. While the measurement indicators vary, consistent results indicate that the STEM approach is effective in enhancing these competencies. This suggests that, despite differences in approaches and subject focus, the core of STEM implementation lies in its ability to drive the improvement of more holistic skills, preparing students to face complex challenges in an increasingly technology-integrated world (Beers, 2011).

Therefore, despite significant differences in the application of teaching models, subject selection, and measured indicators, the success of STEM implementation can be seen in its ability to consistently enhance various aspects of learning that are relevant to today's needs. This highlights the flexibility of STEM in supporting the development of comprehensive skills in students, which are directly aligned with global challenges. Based on the analysis results, several key findings emerge from this study, including: a) the benefits of implementing the STEM approach in high schools, b) the supporting and inhibiting factors for STEM implementation in high schools in Indonesia, and c) recommended effective strategies for implementing STEM in Indonesia.

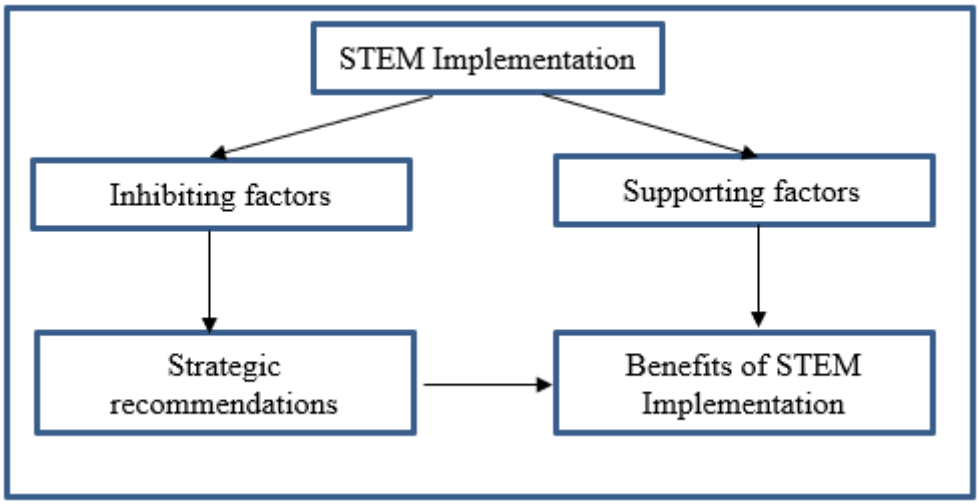

Figure 2. The relationship between STEM implementation, supporting and inhibiting factors, strategies, and the benefits of STEM implementation

Benefits of Implementing the STEM Approach in Indonesian High Schools

RQ 1: What are the benefits of implementing the STEM approach in high school education?

STEM (Science, Technology, Engineering, and Mathematics) has become a new paradigm in education, particularly at the high school level, aimed at creating learning experiences that are relevant to the needs of the 21st century. By integrating various disciplines, this approach offers a learning experience oriented toward real-world applications, bridging the gap between theory and practice. The STEM approach is highly relevant to constructivist learning theory and Vygotsky's theory of cognitive development. In constructivism, learning is viewed as an active process where students build their own knowledge through interactions with the environment and hands-on experiences (Piaget, 1973). STEM-based projects support this principle by engaging students in exploration, experimentation, and problem-solving relevant to real-life situations. Through this approach, students create their own understanding by linking new knowledge with prior experiences.

Meanwhile, Vygotsky's theory of cognitive development emphasizes the importance of social interaction in learning, particularly through the concepts of scaffolding and the Zone of Proximal Development (ZPD) (Vygotsky, 1978). In STEM-based learning, scaffolding is realized through gradual guidance provided by teachers or peers, such as initial guidance, triggering questions, or explicit instructions as students work on projects. This support is gradually reduced as students gain independence. Furthermore, STEM projects are designed to be within the students' ZPD, providing challenges that are complex yet solvable with appropriate assistance (Bransford, Brown, & Cocking, 2000). This approach also encourages peer collaboration, where students share knowledge and strategies to solve problems. As a result, students not only master theoretical concepts but also apply this knowledge in real-world contexts, accelerating cognitive development and effectively building critical thinking skills.

As an adaptive learning strategy, the implementation of STEM plays a crucial role in developing resilient youth who are capable of competing in an increasingly complex

and dynamic world (Thovawira et al., 2021). Based on the analysis in Table 1, several benefits of implementing STEM in high schools in Indonesia include:

Improving learning outcomes and scientific attitudes, as evidenced in the study "Application of the STEM Approach in Biology Learning" (2023) and "Efforts to Improve Learning Outcomes on Volta's Cell Concepts" (2022). This research varied several learning methods, including problem-solving, discussions, inquiry, Q&A, and experiments, allowing students to construct their understanding scientifically. The STEM approach provides a learning context that is relevant to real life, enabling students to link theory with practical application. With project- or experiment-based learning models, abstract concepts become easier for students to understand. Practically, these findings imply the importance of integrating STEM into the curriculum, especially for science and mathematics subjects, to bridge the gap between theory and practice.

Enhancing critical thinking skills: The application of STEM in high schools has consistently proven effective in improving students' critical thinking abilities. The study "The Effect of STEM-Fishbone Diagram Learning" (2022) shows that the use of a Fishbone diagram based on STEM enhances students' critical thinking skills. By focusing on the integration of science, technology, engineering, and mathematics in the learning process, students are encouraged to use logical methods to solve problems, analyze information, and hone their critical thinking skills. By encouraging cross-disciplinary integration, students are not only trained to understand the material but also to develop systematic and structured thinking. This helps students become independent learners who are able to face real-world challenges with a structured and systematic approach.

Increasing interest and motivation in learning: The STEM approach boosts students' interest and motivation through more interactive and relevant learning experiences. Combining STEM with blended learning, as reported in "The Impact of Using STEM Education Approach with Blended Learning" (2020) and "Application of STEM-Based Blended Learning to Cognitive Abilities" (2023), creates a more engaging learning experience. The use of technology, simulations, and interactive methods not only makes learning more dynamic but also provides broader access for students with diverse learning needs. The implication is that the government needs to provide technological infrastructure and supporting resources, particularly in remote areas, so that STEM-based blended learning can be accessed equitably.

Enhancing students' creativity: Through project-based learning, students are encouraged to generate innovative and creative solutions to real-world problems, such as developing technology-based tools. Research on "Improving Students' Creativity in Statistics Material through PjBL-STEM Learning Model" (2019) shows that this method stimulates computational thinking skills and encourages students to think "outside the box". This application is relevant for preparing Indonesia's youth to face the Industry 4.0 revolution with strong innovation and collaboration skills.

Overall, the benefits of implementing the STEM approach in high schools not only include improvements in learning outcomes and student skills but also contribute to a paradigm shift in education in Indonesia. To maximize its impact, policy support is needed to promote teacher training, the development of STEM-based curricula, and the provision of adequate facilities and infrastructure. With these steps, the STEM approach can serve as a catalyst for transforming Indonesian education towards more adaptive, relevant, and globally competitive learning.

Supporting Factors and Inhibiting Factors for the Implementation of the STEM Approach in in Indonesian High Schools

RQ 2: What are the supporting and hindering factors in the implementation of the STEM approach in high schools?

The implementation of the STEM (Science, Technology, Engineering, and Mathematics) approach in high schools is influenced by various supporting factors that contribute to its successful application. One of the key factors is the availability of technology and interactive learning media, such as Android-based applications and blended learning methods. These media allow students to better understand abstract concepts through visualization and interactive experiences that are relevant to daily life. Hulwani et al., in their research "Development of Interactive Android Learning Media with a STEM Approach on Trigonometry Material" (2021), found that the use of Android applications in trigonometry material improved students' interest and understanding, while the study by Ardianti et al. "The Impact of Using the STEM Education Approach with Blended Learning to Increase Students' Learning Interest" (2020) demonstrated that the combination of STEM and blended learning significantly increased students' learning interest. This technology enables students to connect abstract concepts with real-world applications, making learning more engaging and meaningful (Pramadanti et al., 2021).

Additionally, teacher training and workshops are crucial elements for supporting the implementation of STEM. These training sessions provide teachers with the skills to design STEM-based lessons, use technology effectively, and assess the success of the learning process. The STEM approach also aligns with the national competency-based curriculum, which encourages the development of 21st-century skills such as critical thinking, creativity, and collaboration. Puspita et al. (2022), in their study, demonstrated that using the STEM model with Fishbone diagrams improved students' critical thinking and self-efficacy, while Surya et al. (2018) reported that STEM-based learning enhanced creative thinking skills in the topic of the law of gravity. With the synergy of these factors, STEM implementation in high schools can optimize education quality and better prepare students for global challenges (Estriyanto, 2020).

In addition to the supporting factors, hindering factors must also be considered. One significant challenge is the lack of facilities and infrastructure in remote areas. A shortage of laboratories, technological devices, and internet access poses a major obstacle to the widespread implementation of STEM. Wahyuni (2022) noted that these facility limitations often reduce the effectiveness of STEM-based learning, particularly in topics requiring experiments and direct application. Furthermore, the insufficient competency of teachers in designing and implementing STEM-based learning is another significant barrier, as identified by Fauziah et al. (2024), who emphasized that additional training is needed to improve students' computational thinking skills.

Another hindering factor is resistance to change, both from students and teachers, who are often comfortable with traditional teaching methods. Lydiati (2019) highlighted that the success of STEM-based learning through project-based learning requires efforts to shift the learning paradigm from passive to active. This demands stronger policy support, such as providing dedicated budgets, procuring technological facilities, and offering incentives for teachers who actively adopt the STEM approach.

By understanding these supporting and hindering factors, strategic measures can be taken to optimize STEM implementation in high schools. Continuous policy support, the provision of adequate infrastructure, and intensive teacher training are key to ensuring that the STEM approach can have a positive and widespread impact across Indonesia. These obstacles need to be addressed with strategic solutions to ensure that STEM implementation proceeds optimally in all schools (Kamal, 2024).

Effective Strategies for Implementing the STEM Approach in Indonesian High Schools

RQ 3 : What are the recomended effective strategies for implementing the STEM approach in Indonesian high schools?

The implementation of the STEM (Science, Technology, Engineering, and Mathematics) approach in high schools requires an integrated strategy to improve the quality of education. One important step is the development of a STEM-based curriculum that supports interdisciplinary learning through project-based approaches and the integration of technology. This curriculum is designed to combine elements of science, technology, engineering, and mathematics to create learning that is relevant to the real world (Mustofiyah et al., 2024). Research by Putri, Mulyani, and Husna (2023) shows that the STEM approach effectively improves student learning outcomes and scientific attitudes, particularly in Biology education. To support the success of this implementation, government policy support, including funding for the procurement of learning tools, development of innovative media, and regular monitoring, is essential for the successful implementation of STEM in schools (Wahyuni, 2022).

Teacher training is a crucial aspect of this strategy. Teachers need to undergo training that includes a deep understanding of STEM concepts, the integration of technology in the teaching process, and project-based learning techniques, as recommended by Surya, Abdurrahman, and Wahyudi (2018), who emphasized that project-based teaching can enhance students' creative thinking skills. Teachers must also apply a collaborative approach across subjects to create more holistic and relevant learning experiences (Sudarmin et al., 2022). The use of innovative learning media, such as interactive applications, digital modules, or animated videos, can help teachers deliver content in an engaging and effective manner. Ongoing training will ensure that educators remain capable of keeping up with technological advancements and the ever-evolving needs of education (Nugraheni et al., 2022).

Teacher training in areas with limited facilities can be adapted through simple yet effective strategies. One approach is to utilize lightweight technology, such as mobile-based applications or printed modules for self-training, allowing access to materials without the need for complex digital infrastructure (Kusnadi et al., 2024). A community-based approach is also relevant, where teachers can share knowledge through local training sessions facilitated by experts to foster collaboration and mutual empowerment (Puspita et al., 2022). Additionally, integrating local materials into project-based learning offers practical solutions, enabling teachers to implement STEM even with limited resources (Lydiati, 2019).

Collaboration between educational institutions and the industrial world is also a vital part of the STEM implementation strategy. Schools can collaborate with companies or research institutions to provide students with real-world experiences through actual

projects, field visits, or internships (Yusuf & Asrifan, 2020). Through these experiences, students will gain a deeper understanding of how STEM concepts are applied in the professional world, while also being motivated to explore careers in science and technology (Sinaga, 2023). By utilizing a combination of these strategies, it is hoped that the implementation of STEM will have a significant positive impact on improving the quality of education and assisting students in facing the challenges of the 21st century (Fadillah, 2024).

▪ CONCLUSION

Overall, the implementation of STEM at the high school level shows a significant impact on the development of students' abilities. This approach not only improves students' understanding of academic concepts, but also builds critical thinking skills, creativity, and problem solving that are relevant to the challenges of the 21st century. The integration of technology-based learning and interdisciplinary projects provides a more interesting and applicable learning experience for students, thereby increasing their motivation and interest in the lessons. In addition, the implementation of STEM also opens up opportunities to develop innovations in the teaching and learning process that are more inclusive and responsive to the needs of the digital era..

However, the implementation of STEM in high schools still requires strong support from various parties such as schools, teachers, and related stakeholders. In reality, the implementation of STEM in high schools still faces many obstacles. As a recommendation, it is suggested that training and coaching for teachers in implementing the STEM approach continue to be improved. In addition, it is important for schools to provide facilities and equipment that support the implementation of the STEM approach and collaborate with industry and the private sector.

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