Diversification of STEM (Science, Technology, Engineering, and Mathematics) Integrated Learning Models as an Innovation in Vocational Learning in the *Merdeka Belajar* Era

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Abstract

This research presents a study on the implementation of STEM (Science, Technology, Engineering, and Mathematics) education in the context of vocational education in the era of independent learning, emphasizing self-directed learning. Through qualitative descriptive methods and literature review analysis, this study highlights the transformation of conventional teaching paradigms into more dynamic, creative approaches focused on developing students' problem-solving skills. The research findings confirm the improvement of students' competencies, including planning, design, reflection, construction, and modification aspects of STEM projects. Another significant discovery is that integrating STEM with other teaching models such as Project-Based Learning (PjBL) or Problem-Based Learning (PBL) effectively enhances students' critical thinking, creativity, communication, and collaboration skills regardless of gender. In conclusion, the implementation of STEM education not only prepares vocational education students to face the challenges of the 21st century and the era of independent learning but also stimulates students' interest and engagement in learning, promotes inclusivity, and enhances the overall quality of education.
Keywords: *Learning Models, STEM, Vocational Education*

Introduction

With a population exceeding 200 million people, Indonesia has a significant obligation to create a high-quality and competent Human Resources (HR) base, enabling it to compete competitively with other countries on the international stage. One crucial approach to advancing the quality of HR is through substantial improvements in the education system. Education stands as a fundamental pillar in the nation's development, and a nation's progress is often reflected through its well-implemented education system (Erlinawati et al., 2019; Maulana, 2020; Septiani, 2016). Education can be seen as a long-term investment in the nation's future, where students are taught to play a vital role in creating a sophisticated, knowledgeable, and morally strong society (Daulai & Rosdiana A. Bakar, 2021; Hidayat & Abdillah, 2019).

One integral strategy in creating high-quality Human Resources is through the enhancement and recalibration of the education system. Education, in this context, occupies a significant portion and serves as the main element in shaping individuals who not only possess excellent capabilities but can also adapt to the rapid changes and advancements in the ever-evolving world. Furthermore, the role of education is not just essential but also dominant in measuring the progress or regression of a nation. As expressed by Strimel & Grubbs (2016)education plays a central role in improving the quality of HR, especially within the framework of national development. Therefore, genuine efforts to improve the quality of education provided in schools are strategic steps in producing a better HR. Education, as the primary vehicle for HR development, aims to mold students into individuals who are not only productive but also possess exceptional professional abilities to contribute to the improvement of the nation's quality of life. Moreover, education is also depicted as a cultural process that helps enhance human dignity and honor through a series of lifelong learning experiences.

One learning method that can support vocational education goals is the implementation of STEM (Science, Technology, Engineering, and Mathematics) education. In the Indonesian Dictionary (KBBI), each of these four fields in STEM has a unique definition: Science is systematically acquired knowledge through observation, research, and experiments aimed at understanding the principles of the studied object. Technology refers to all tools and materials used to produce goods necessary for human life. Engineering describes the approach or system used to carry out specific actions or tasks. Mathematics is the science that focuses on numbers, relationships between numbers, and operational procedures used in problem-solving involving numbers.

The emergence of the STEM education reform movement can be traced back to various research findings indicating a lack of potential candidates capable of filling crucial positions in the STEM sector, coupled with low scientific literacy levels and unsatisfactory achievements of American high school students in TIMSS and PISA tests (Ritz & Fan, 2015). Additionally, the United States has acknowledged that its economic growth is slowing down and faces threats from China and India, which excel in the fields of science, technology, engineering, and mathematics.

The STEM approach is an in-depth educational strategy that integrates the four main domains: Science, Technology, Engineering, and Mathematics, with an emphasis on practical application in addressing interrelated problems in everyday life and career perspectives. Through STEM education, participants are taught concepts, principles, and methodologies that integrate these four components to develop products, processes, and systems that significantly benefit human development and their professional advancement. In this STEM framework, Science functions as a discipline based on systematic observation and measurement of natural phenomena to provide objective explanations about continuous changes. Technology, on the other hand, encompasses human innovations designed to alter the natural environment to meet various human needs and desires, thereby enhancing comfort and resilience in life. Engineering, as another component in STEM, involves understanding and applying scientific knowledge, economic factors, social aspects, and best practices in the design and production of machines, equipment, systems, materials, and procedures that have positive impacts economically and sustainably. Lastly, mathematics involves identifying patterns and relationships and provides the language and tools used to describe the aspects of technology, science, and engineering in depth.

The STEM education approach aims to prepare students to compete and enter the workforce according to their expertise. Based on research by the Hannover research institution in 2011, STEM education's main goal is to demonstrate comprehensive knowledge in various STEM subjects. At the primary and secondary education levels, STEM education seeks to develop students' abilities to understand and apply STEM literacy (Honey et al., 2009). This involves the ability to identify questions and problems in everyday life, explain natural phenomena, design, and draw conclusions based on relevant evidence related to STEM issues. Additionally, students are expected to understand specific characteristics within STEM disciplines as forms of human knowledge, inquiry, and design and be aware of STEM disciplines' influence on material, intellectual, and cultural environments. They are also encouraged to actively explore STEM-related issues, such as energy efficiency, environmental quality, and natural resource limitations, as proactive, caring citizens capable of considering scientific, technological, engineering, and mathematical concepts.

STEM education focuses on developing STEM literacy in students to prepare them to master highly relevant skills and knowledge in the 21st century. This includes the ability to think critically, unleash creativity, conduct in-depth analyses, as well as foster effective communication and collaboration skills in the contexts of science, technology, engineering, and mathematics. Additionally, STEM education also strategically aims to strengthen the workforce's readiness in the STEM sector to meet the growing demands of the job market in the modern era guided by technological advancements. This approach is expected to inspire students' interest and engagement in learning processes because they will clearly see the relevance and practical application of the materials they are learning. In a broader context, STEM education also focuses on helping students build strong connections between STEM concepts and their everyday life situations, enabling them to link theory with tactical applications in the real world. Thus, students will be equipped to face complex challenges and be prepared to respond to the dynamics of the modern job market with all its changes.

The goal of STEM learning for teachers is to enhance their understanding and mastery of STEM content, including science, technology, engineering, and mathematics. Teachers are expected to deepen their knowledge in each of these scientific disciplines and understand the relationships between them. Another goal is to enhance teachers' Pedagogical Content Knowledge (PCK) in the context of STEM. This includes teachers' skills in designing and implementing effective and relevant teaching strategies to deliver STEM materials to students. By strengthening PCK, it is expected that teachers can create motivating learning environments that enable students to better understand and apply STEM concepts. Through training and developing PCK, teachers are also expected to overcome challenges that may arise in the STEM learning process. Therefore, the goal of STEM learning for teachers is to prepare them to be competent and effective educators in guiding students toward mastering STEM concepts.

The definition of STEM education is adopted as an interdisciplinary approach in learning because it provides educators with the opportunity to show students how STEM concepts, principles, and techniques are integrated into the creation of products, processes, and systems used in everyday life (Avery & Reeve, 2013; Reeve, 2013). To develop STEM literacy so that students can compete in the 21st century, STEM-based learning involves the use of science, technology, engineering, and mathematics in the context of the real world. Guzey et al. (2016), Havice et al. (2018) & Stohlmann et al. (2012) identified four aspects that educators need to consider for smooth implementation of STEM education. These four aspects can be explained through the illustration below.

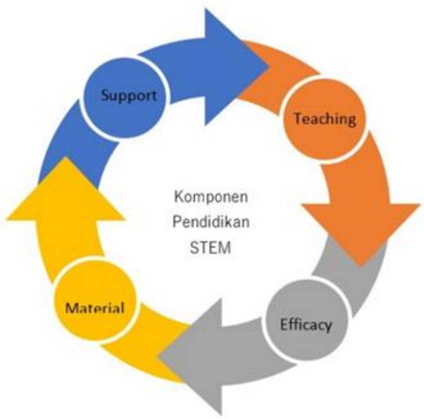

Fig. 1. Elements supporting STEM education.

Factors that provide essential support or supportive aspects related to the implementation of STEM education can encompass various comprehensive elements. These include engagement in appropriate training, collaboration with other entities or institutions such as universities or the industrial sector, as well as opportunities for collaboration with fellow educators in the same school. Meanwhile, in the category of teaching factors, the focus is on the preparation and implementation of learning within the classroom. These factors include preparing relevant teaching materials and effectively applying them in the classroom environment. Furthermore, success factors are reflected in the educators' confidence in conducting STEM education. This confidence can be influenced by their deep understanding of the subject matter and their perseverance in implementing effective teaching methods. Lastly, in the context of facility factors, attention is given to the availability of essential facilities and supporting equipment in conducting quality STEM education.

Method

The method employed in writing this article is a Literature Review. The research was conducted from October to November 2023. The study utilized data from Google Scholar over the past ten years (2013-2023). The selected journals had full access to PDFs and were in both Indonesian and English languages. The search yielded 7,890 journals with the keywords "application of STEM in Learning Models." These results were filtered to 41 journals relevant to innovative STEM-based learning models, assessed based on their titles, keywords, and abstracts. Further refinement narrowed down the selection to 20 journals specifically related to variations of STEM-integrated learning models, considering the overall content of the texts. These 20 journals will be used in the research and writing process. By conducting a literature review, the researcher can leverage all relevant information and thoughts related to the study. Based on the literature found, an analysis was performed on aspects related to the importance of STEM in vocational education learning models. Consequently, it is anticipated that results related to innovative learning models integrated with STEM in vocational education will be obtained.

Results

Research exploring the STEM field has achieved in-depth exploration, not only at the national level but also internationally, and the results have yielded remarkably positive findings. For example, in the study "Introducing STEM Education: Implication for Educating Our Teacher for the Age of Innovation," findings indicate that the STEM learning approach can bring about fundamental changes in the previously conventional teaching paradigm, transforming it into a much more dynamic, creative approach focused on developing fundamental problem-solving skills (Corlu et al., 2014; EL-Deghaidy et al., 2017). These findings align with significant shifts in recent educational curricula, such as the revised 2013 curriculum, emphasizing the importance of student participation in the learning process, allowing room for student expression and creativity through an emphasis on the interaction between mathematics and science in the STEM domain, and emphasizing the four core disciplines (science, technology, engineering, and mathematics) to address various problem-solving challenges faced in the current era. At the national level, in Indonesia, studies focusing on innovation in science education have arrived at significant conclusions, emphasizing that the STEM approach has the potential to serve as a strong foundation for developing 21st-century skills. These skills are known as the 4C Skills, including Communication Skills, Collaboration Skills, Critical Thinking Skills, and Innovation and Creativity Skills. These skills play a highly relevant role in the context of education that promotes self-directed learning in the present era (Permanasari, 2016; Permanasari et al., 2021).

Research titled "Integration of STEM in Grade Six: Designing and Building Paper Bridges" drew the conclusion that there was a positive response from students manifested through their ability to design and build optimal paper bridges (English & King, 2019). These findings illustrate that the STEM approach significantly enhances students' competence in various aspects such as planning, design, reflection, construction, and project modifications. Research exploring "STEM Education to Meet the Challenges of the 21st Century" concludes that STEM has universal relevance, can be effectively applied both domestically and internationally, and aligns with the demands of the current era ((Hanna Widayani, 2017; Sutaphan & Yuenyong, 2019; Widayanti et al., 2019; Widya et al., 2019). This indicates that students engaged in the STEM approach possess significant competitive abilities and relevant competencies in various fields of concern. Studies examining "STEM Education: Potential of Educational Technology" show that STEM has great potential in overcoming various obstacles and challenges in the context of educational technology and also has a substantial positive impact on students' abilities (K. Daugherty & Carter, 2019). This illustrates that STEM is not only an innovative solution but also a strong contributor to enhancing students' competencies and skills in the era of educational technology.

Discussion

Students benefit greatly from STEM education. Firstly, and most importantly, STEM education leads to improved learning and academic performance, the ability to solve complex problems, and enhanced critical thinking skills. Furthermore, STEM education provides students with opportunities to cultivate perseverance and resilience in learning, crucial for their success in achieving higher accomplishments. Students are better prepared to engage in jobs requiring knowledge and skills in the fields of mathematics, science, technology, and engineering. Moreover, students' interest in STEM fields increases as they attempt to perceive the relevance and practical application of the concepts they learn. Additionally, students develop a strong STEM identity and face challenges in STEM fields with confidence and proficiency. The ability to connect between STEM disciplines also becomes a skill for students, enabling them to integrate knowledge from various disciplines to solve more complex problems. Therefore, the outcomes for students receiving STEM education result in positive impacts on all aspects of their lives.

Research published by (Octaviyani et al., 2020; Widana, 2021) indicates that the implementation of STEM-based project-based learning affects the creativity levels of vocational high school students. This research concludes that vocational high school students' average creative thinking ability significantly improves after participating in STEM PjBL (Project-based Learning). Furthermore, the test analysis shows a significant difference between students' abilities before and after STEM PjBL learning.

These findings are consistent with the results of Lou et al. (2017) on creativity in STEM learning, focusing on projects inspired by the history of steamships. The research results demonstrate that students' creative abilities can be significantly enhanced by implementing five core stages of STEM project-based learning: planning, implementation, presentation, evaluation, and correction. These findings reinforce the idea that students' creativity can be constructively developed if STEM learning strategies are well planned and executed, from planning to assessment and adjustment.

Another relevant study was conducted by Kristiani et al. (2017). This research revealed that STEM-based learning integrated with the PjBL (Project-based Learning) model has the potential

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to enhance students' creative thinking skills, even to a high level. This finding is in line with research examining the integration of STEM education, as outlined in a systematic review of learning practices at the secondary education level (Thibaut et al., 2018). The study asserts that to achieve optimal results, the STEM approach needs to be combined with various other learning models, such as problem-based learning, inquiry-based learning, design-based learning, or collaborative learning. The clear conclusion from these three studies is that integrating the STEM learning approach with appropriate learning models significantly enhances students' creative potential, provided the planning is comprehensive and in line with the stages in STEM learning.

Afriana et al. (2016) & Kristiani et al. (2017) stated that research exploring STEM teaching methods can smoothly integrate into various existing learning models, including cooperative learning, problem-based learning (PBL), project-based learning (PjBL), and various other learning models. Research focused on implementing project-based learning in STEM and considering gender aspects to improve students' science literacy proves that there is no significant difference in science literacy between male and female students. Positive responses from students (both male and female) indicate that all students are actively engaged in STEM learning and enjoy every stage of the process, encouraging their interest in the learning process. In the context of STEM learning, students can sharpen their presentation skills through various presentation methods and can enhance their critical thinking capacity without gender differences, both for male and female students.

STEM-related research in Indonesia shows positive results, where classes using the STEM approach significantly enhance students' multipresentation skills compared to students following scientific methods. These findings align with the research titled "Implementation of Science, Technology, Engineering, and Mathematics (STEM) Approach to Improve High School Students' Multipresentation Skills in the Context of Newton's Law of Motion" by Mulyana et al. (2018). Although the 2013 curriculum emphasizes a scientific approach, this research demonstrates that the STEM approach also has a significantly positive impact on improving students' multipresentation skills. Therefore, in the implementation of the 2013 curriculum, the STEM approach can be an option alongside scientific method.

Rahmadhani & Wahyuni (2018)) show that the use of the STEM approach can also be applied at the university level. Here, the STEM approach enhances students' conceptual understanding and learning interest. This indicates that at the university level, the STEM approach can be effectively applied. There is a positive relationship between students' initial abilities and the application of the STEM approach in influencing conceptual understanding, although students' learning interest is not significantly affected. This means that university students may not have a high interest in STEM learning, but this approach can positively enhance their understanding during the learning process.

Based on the research conducted by researchers, both domestically and internationally, the STEM learning method receives positive recognition. When combined with other models such as Project-Based Learning (PjBL) or Problem-Based Learning (PBL), STEM education has a positive impact, including improved critical thinking, creativity, communication, and collaboration skills, which are crucial in this 21st-century era. Although there is no specific research on this in Indonesia, STEM education can be effectively implemented in vocational education, especially after its successful application in science and mathematics education. The hope is that this step can enhance the quality of vocational school graduates and reduce unemployment rates in Indonesia

Conclusion

STEM research yields positive and significant findings, exploring diverse learning approaches' impact on students across educational levels. STEM education transforms traditional teaching, fostering dynamic, creative problem-solving skills. Results highlight enhanced competence in planning, design, and critical 4C Skills (Communication, Collaboration, Critical Thinking, Innovation) crucial for 21st-century education. In Indonesia, STEM combined with models like Project-Based Learning proves effective in boosting critical thinking, creativity, and communication skills, anticipating improved vocational education quality and reduced unemployment.

Integration with PjBL or PBL elevates creative thinking significantly. Gender-neutral outcomes signify active engagement, emphasizing STEM's broad positive impact, preparing students for 21st-century challenges and driving future-relevant, competitive education.

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