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Evaluation of STEM Integration in Science Teaching Materials: An Independent Curriculum Perspective

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ABSTRACT

Purpose of the study: This study aims to evaluate the level of integration of STEM components in the science teaching materials of the Independent Curriculum. The focus of the evaluation includes the dimension of integration between STEM disciplines as well as the relevance of the learning context to real-world problem solving.

Methodology: The research uses a qualitative descriptive method, analyzing 31 science learning modules using the Bybee STEM evaluation model. Data were collected through document analysis with a focus on the variables of coordination, combination, and linkage of STEM disciplines.

Main Findings: The results show that science is dominant as the main context (100%) with the integration rate of technology and mathematics at 77% and 61%. However, the engineering aspect is only integrated by 23%, indicating a lack of attention to engineering design.

Novelty/Originality of this study: This research provides new insights into the challenges of STEM implementation in Indonesia, especially in the context of developing balanced and comprehensive science teaching materials.

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1. INTRODUCTION

The complexity of the future workforce demands education that integrates STEM (Science, Technology, Engineering, Mathematics) to build 21st-century skills such as problem-solving, critical thinking, and collaboration. STEM-based education is designed not only to enhance literacy in science, technology, engineering, and mathematics but also to prepare students for the increasingly complex and technology-driven challenges of the real world [1], [2].

However, the implementation of STEM in Indonesia still faces several significant challenges. One of the main obstacles is the low level of STEM literacy among students and teachers, which is fundamental to the success of STEM education. Many teachers in Indonesia struggle to apply the STEM approach due to a lack of adequate professional training and limited understanding of interdisciplinary STEM integration [3], [4]. Furthermore, the lack of supportive learning resources, such as STEM-based modules or teaching materials, has also become a barrier to the optimal implementation of this learning approach [1], [5], [6].

These challenges are further exacerbated by the misalignment between the current curriculum and the needs of STEM-based learning. Although the Kurikulum Merdeka provides opportunities to develop interdisciplinary approaches, the adoption of STEM in teaching contexts remains limited, especially in regions with restricted access to teacher training and educational resources. Therefore, a comprehensive evaluation is needed to assess the extent to which STEM literacy has been integrated into teaching modules, particularly within the context of Kurikulum Merdeka, in order to identify areas for improvement and develop more effective implementation strategies.

Kurikulum Merdeka offers flexibility for teachers to design STEM-based learning, emphasizing interdisciplinary approaches relevant to real-world contexts. This approach aims not only to enhance students' cognitive competencies but also to develop practical skills that support their readiness to face global challenges. In this context, Kurikulum Merdeka presents significant opportunities for the development of teaching materials that holistically integrate science, technology, engineering, and mathematics [7].

However, research indicates that the implementation of STEM discipline integration in practice remains suboptimal, with a predominant focus on science [8], [9]. Technology and mathematics disciplines often serve merely as supporting elements, while the engineering discipline tends to be overlooked in instructional design. This imbalance highlights limitations in teachers' understanding and skills in fully integrating the STEM approach. This gap underscores the urgency to evaluate the extent to which STEM has been integrated into the teaching materials used by educators within the Kurikulum Merdeka framework. By understanding this level of integration, this study aims to provide strategic recommendations to enhance the quality of STEM-based teaching materials, particularly in science subjects, to support the development of 21st-century competencies among students.

Therefore, this study aims to evaluate the level of STEM component integration in science teaching materials within the Kurikulum Merdeka framework. The evaluation focuses on the dimensions of interdisciplinary integration among STEM disciplines and the relevance of the learning context to real-world problem-solving. The results of this study are expected to provide strategic recommendations for improving the quality of STEM-based science teaching materials, thereby supporting the development of students' competencies in addressing increasingly complex global challenges.

2. RESEARCH METHOD

This study employed a qualitative descriptive approach aimed at analyzing the level of STEM component integration in science teaching modules. A qualitative descriptive design is a research approach that seeks to provide a clear and comprehensive description of a phenomenon [10]. This approach was chosen as it allows researchers to thoroughly describe and interpret data within the context of the implementation of Kurikulum Merdeka. The analysis was conducted on 31 science teaching modules used by teachers in various schools that have adopted Kurikulum Merdeka. These modules were systematically analyzed using a document evaluation method, focusing on identifying patterns of integration among STEM disciplines (science, technology, engineering, and mathematics) in the materials and learning activities presented.

This study also considered the relevance of the modules to real-world contexts, including their ability to facilitate students in solving complex and interdisciplinary problems. Data collected through document analysis were categorized based on evaluation indicators encompassing the dimensions of coordination, combination, and interconnection among STEM disciplines, providing a comprehensive overview of the quality of STEM integration in science teaching materials. The teaching modules were analyzed using indicators adapted from Bybee's model [11], focusing on three main dimensions of STEM integration: 1) Coordination: Synchronization between disciplines; 2) Combination: Integration of various disciplines through project-based learning; and 3)Interconnection: Relationships among science, technology, engineering, and mathematics. This study was conducted through several systematic stages to evaluate STEM integration in science teaching modules under the Kurikulum Merdeka framework. The research stages included: Collecting modules from teachers in the Cikembar subdistrict, Analyzing STEM integration using a standardized evaluation table, and Categorizing results based on the percentage of STEM discipline integration.

3. RESULTS AND DICUSSION

3.1 STEM Integration Level in Learning Modules

The analysis results show that science serves as the primary context (100%). The integration of technology and mathematics reached 77% and 61%, respectively, while the integration of the engineering aspect was only 23% (Table 1).

Tabel 1. STEM Integration in Science Teaching Modules

Disciplines	Coordination	Combination	Interconnection	(%)
Science & Technology	19%	23%	42%	77
Science & Mathematics	19%	13%	19%	61
Science & Engineering	16%	10%	23%	55

The analysis results show that STEM integration in the science teaching modules of the Kurikulum Merdeka is still unbalanced among the involved disciplines. The teaching modules consistently use science as the primary context, with an integration level reaching 100%. This indicates that the applied STEM approach is more focused on teaching science concepts, while other disciplines—such as technology, mathematics, and engineering—tend to play a supporting role.

Integration of Science and Technology (77%)

The teaching modules show relatively high levels of coordination, combination, and interconnection between science and technology, with a total integration of 77%. This reflects a fairly good effort in utilizing technology to support science learning, such as through the use of digital tools or technological applications in experiments. However, the interconnection value of 42% indicates that the relationship between science and technology is still often partial, not fully integrated within the context of STEM-based problem-solving.

Integration of Science and Mathematics (61%)

The integration of science and mathematics has a lower percentage, at 61%. This is due to the low values of combination (13%) and interconnection (19%). This limitation indicates that the modules have not optimally utilized mathematics as a tool for analysis or problem-solving in science education. However, mathematics plays a crucial role in helping students model scientific phenomena, analyze data, and present results quantitatively.

Integration of Science and Engineering (55%)

The integration between science and engineering is at the lowest level, with a total percentage of 55%. The coordination (16%), combination (10%), and interconnection (23%) values indicate that the engineering aspect is often overlooked in the teaching modules. This may be due to the limited teacher training in developing engineering-based activities, such as the design of authentic technological solutions. However, the engineering approach is highly relevant for enhancing students' critical and creative thinking skills.

The findings of this study are consistent with previous research, which shows that STEM integration in science education is often dominated by the science discipline as the primary context. Permanasari et al. (2023) also revealed that STEM implementation in Indonesia tends to focus on teaching science concepts, while other disciplines, such as technology and engineering, are often positioned as supportive elements rather than being an integral part of the learning process. This study further emphasizes that engineering remains an underemphasized aspect in STEM-based learning design, with only 55% integration in the modules analyzed.

These results also align with Rubini et al, who found that the low STEM literacy among teachers contributes to the lack of balance in STEM discipline integration [4]. Teachers often struggle to connect science with technology, mathematics, and engineering due to the lack of professional training focused on a holistic STEM approach. This is reflected in this study, where the low combination values (10% for science and engineering, and 13% for science and mathematics) highlight the lack of cross-disciplinary project-based activities designed to effectively integrate various STEM elements.

Furthermore, Kelley and Knowles, argued that the ideal STEM approach should involve problem-based projects that not only connect various disciplines but also are relevant to real-world contexts [9]. In this study, the low interconnection values (42% for science and technology, 23% for science and engineering) indicate that the existing teaching modules do not fully reflect these characteristics. This suggests that although efforts have been made to integrate STEM, the learning still focuses on theory without sufficiently emphasizing authentic practical applications.

This study reinforces previous findings regarding the challenges of STEM implementation in Indonesia, while also providing new insights by analyzing in detail the level of STEM integration in science teaching modules under the Kurikulum Merdeka framework. Thus, this research provides empirical groundwork for developing better strategies to integrate STEM disciplines, particularly through enhanced teacher training and the development of more balanced STEM-based teaching materials.

3.2. Challenges in STEM Implementation

The results of this study show that the engineering aspect has the lowest level of integration compared to other STEM disciplines, with only 23% integration in the teaching modules. This lack of engineering integration indicates a significant challenge in STEM implementation, particularly in adopting engineering design as part of learning activities. Engineering is a key component of STEM that plays an essential role in solving design-based problems and building innovative solutions [7], [12]-[14]. However, these results confirm that the engineering-based approach is still underrepresented in school-level education.

These findings are consistent with the research by Rubini et al, which states that the low level of engineering literacy among teachers is one of the main factors hindering the integration of engineering into science education [4]. Teachers often face limitations in understanding basic engineering concepts, which leads to a lack of confidence in designing and implementing engineering-based learning activities. This issue is further exacerbated by the scarcity of professional development programs specifically focused on enhancing engineering skills within STEM education. In the context of this study, the low combination value (10% for science and engineering) further indicates that cross-disciplinary project-based activities involving engineering are not yet common practice among teachers.

The research by Kelley and Knowles, also emphasizes that one of the key elements for the successful implementation of STEM is providing teachers with training and resources to effectively understand and integrate engineering [9]. Without adequate training, teachers tend to adopt a fragmented approach, where each STEM discipline is taught separately without strong connections. This aligns with the findings of Permanasari et al, who state that teaching modules in Indonesia tend to emphasize science as the primary discipline, while engineering is often treated merely as a supporting element [1].

Additionally, the research by Ring et al, highlights that one of the main challenges in STEM implementation is the low availability of teaching materials that explicitly support engineering-based activities [2]. In the context of this study, the analyzed teaching modules still provide limited opportunities for students to design engineering-based solutions relevant to real-world challenges. For example, activities such as prototype design or engineering design evaluation are rarely found in the modules, reducing the opportunities for students to develop the critical and creative thinking skills associated with engineering.

3.3 Implications for Curriculum Policy

The findings of this study provide important insights for the development of curriculum policies that better support the implementation of STEM in Indonesia. One of the key recommendations is the development of more integrated teaching modules, ensuring that all STEM disciplines (science, technology, engineering, and mathematics) are balanced and integrated. These integrated teaching modules are not only crucial for enhancing the relevance of learning to real-world contexts but also for ensuring that students receive a comprehensive and interdisciplinary learning experience.

This recommendation is consistent with the research by Kelley and Knowles, which emphasizes that an effective STEM approach requires close integration between disciplines, rather than teaching them separately [9]. This study also supports the findings of Permanasari et al, which show that STEM implementation in Indonesia tends to focus on science as the primary discipline, with limited attention given to technology and engineering aspects [1]. Therefore, the modules developed need to be designed to strengthen the connections between disciplines, for example, through problem-based projects that involve designing technology or engineering-based prototypes.

Moreover, teacher training is a key element in ensuring the success of STEM implementation. Teachers play a central role in designing and implementing STEM-based learning, so training focused on engineering design and the utilization of technology should be prioritized [1], [5]. Rubini et al, found that low STEM literacy among teachers is due to the lack of relevant professional development programs [4]. In the context of this study, intensive training can help teachers better understand how to integrate engineering into science education, while also building their skills in utilizing technology and mathematics as tools to solve complex problems.

The provision of educational resources is also an important aspect that requires policy attention. Ring et al, mention that the lack of access to teaching materials and STEM support tools is one of the main barriers to the implementation of STEM education [2]. In this study, the analyzed teaching modules show that the integration of engineering is still minimal due to the limited availability of teaching materials designed to facilitate engineering-based activities, such as the design or evaluation of technological solutions. Therefore, policy should include the provision of teaching materials designed to support a more holistic STEM implementation, including relevant technological resources for the needs of learning.

Additionally, curriculum policy needs to support the development of flexible curricula that allow teachers to innovate in integrating STEM across various subjects. This study supports the OECD, recommendation, which emphasizes the importance of curriculum flexibility to ensure that STEM-based learning can be tailored to local needs and global challenges [8]. With policies that encourage innovation and the development of STEM-based modules, students can be better prepared to face the challenges of the 21st century, such as rapid technological change and complex environmental issues. Thus, policies focused on the development of integrated modules, teacher training, and the provision of resources supporting STEM can be a strategic step to improve the quality of STEM education in Indonesia. This approach will not only help address the existing challenges in STEM implementation but also prepare students to become competent individuals capable of facing an increasingly complex and technology-driven job market.

4. CONCLUSION

This study shows that STEM integration in the science teaching modules of the Kurikulum Merdeka is still dominated by science, while technology, mathematics, and engineering have not been optimally integrated, particularly in the engineering aspect, which shows the lowest value. The lack of professional training for teachers and the limitations of teaching materials are the main barriers to the holistic implementation of STEM. Therefore, the development of integrated modules that involve all STEM disciplines in a balanced way, teacher training in engineering design, and the provision of resources that support STEM-based learning are necessary. These efforts are expected to prepare students to face real-world challenges with relevant 21st-century skills.

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