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Integration of the STEAM Approach in Learning Within the Merdeka Curriculum at the Elementary School Level: A Systematic Literature Review

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Abstract

This study aims to examine the integration of the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach in primary school learning and to analyze its alignment with the principles of the Merdeka Curriculum. This research employed a Systematic Literature Review (SLR) method guided by the PRISMA 2020 framework to ensure a transparent and structured selection process. The literature search was conducted across multiple academic databases, including Google Scholar, Garuda, and Web of Science, focusing on publications from 2021 to 2025. From an initial pool of 999 articles, 15 studies met the inclusion criteria and were analyzed using qualitative synthesis. The findings indicate that STEAM integration in primary education follows a systematic pattern grounded in constructivist and student-centered learning principles and is primarily implemented through Project-Based Learning (PjBL), Problem-Based Learning (PBL), and inquiry-based learning models. These approaches enable interdisciplinary and contextual learning experiences. Empirically, the implementation of STEAM has been shown to significantly enhance students' 21st century competencies, including critical thinking, creativity, communication, and collaboration, as well as improving science literacy and problem-solving abilities. Furthermore, the STEAM approach demonstrates strong alignment with the Merdeka Curriculum by promoting independent learning, differentiated instruction, and the development of the Pancasila Student Profile. However, several challenges remain, particularly in terms of limited technological infrastructure, time constraints, and teachers' pedagogical readiness in implementing integrative learning. Identified best practices include the use of STEAM-based digital modules, collaborative learning strategies, and continuous professional development for teachers. In conclusion, the integration of STEAM within the Merdeka Curriculum presents a promising framework for enhancing the quality of primary education, although its effectiveness depends on sustained institutional support, teacher capacity building, and adequate technological resources.

INTRODUCTION

Education in the 21st century requires a paradigm shift in instructional approaches, moving beyond mere knowledge transmission toward the development of critical thinking, creativity, collaboration, and communication skills, commonly known as the 4C competencies (Wardani et al., 2025). In this context, learning must be designed to be more adaptive, contextual, and student-centered in order to address increasingly complex global challenges.

One of the most prominent innovative approaches is STEAM (Science, Technology, Engineering, Arts, and Mathematics), which integrates multiple disciplines in an interdisciplinary manner. This approach enables learning to become more meaningful by connecting academic concepts with real-world problems. Research findings indicate that the implementation of STEAM in primary education has a positive impact on students' 21st century skills as well as their academic achievement (Amanova et al., 2025). Furthermore, STEAM contributes to improving technological literacy, critical thinking, and creativity among students (Novi Marliani & Idha isnaningrum, 2025)..

In Indonesia, the Merdeka Curriculum was introduced as a policy response to the need for more flexible and student-centered learning. It provides teachers with greater autonomy to design contextual learning experiences tailored to students' characteristics while strengthening the Profile of Pancasila Students through exploratory and meaningful learning processes (Wardani et al., 2025). Conceptually, the Merdeka Curriculum aligns with the principles of STEAM, particularly in promoting competency-based and student-centered learning.

However, empirical studies reveal that the implementation of STEAM in primary education still faces several limitations. The use of digital media in STEAM-based learning remains suboptimal and is still dominated by conventional approaches (Fadhilah et al., 2024). Additionally, teacher readiness and limited educational facilities continue to be major challenges in its implementation (Malinda et al., 2024). These findings indicate that although STEAM holds significant potential, its integration into classroom practice has not yet been systematically optimized.

Moreover, most existing studies are localized empirical investigations with limited scope, thus failing to provide a comprehensive understanding of the conceptual relationship between STEAM and the Merdeka Curriculum. Although some studies suggest the presence of STEAM integration within Merdeka Curriculum practices, they tend to be descriptive and do not examine the structural alignment between STEAM components and the principles, structure, and objectives of the Merdeka Curriculum (Wardani et al., 2025). In addition, systematic mapping studies that explicitly explore how this integration occurs in primary education remain very limited.

On a global scale, systematic literature reviews highlight that STEAM integration affects not only cognitive outcomes but also student motivation, affective development, and a wide range of competencies (Amanova et al., 2025). Other international studies also emphasize the effectiveness of STEAM in improving students' attitudes, knowledge, and skills at the primary level (Yim et al., 2025). Nevertheless, the dominance of international contexts results in a lack of contextualized understanding regarding the implementation of STEAM within Indonesia's educational framework, particularly in relation to the Merdeka Curriculum.

Based on these considerations, there is a clear need for a more structured and comprehensive literature review that integrates the perspectives of STEAM and the Merdeka Curriculum as a unified educational framework. Such a study is essential not only to identify implementation practices but also to analyze conceptual alignment, integration patterns, and the associated challenges and opportunities within primary education.

Therefore, this study aims to identify and analyze the application of the STEAM approach in primary school learning based on existing literature, while also examining its alignment with the principles of the Merdeka Curriculum from both theoretical and empirical perspectives. Additionally, this research seeks to explore challenges, best practices, and future directions for the integration of STEAM within the Merdeka Curriculum.

Through a comprehensive systematic literature review, this study is expected to provide a clearer mapping of scientific knowledge regarding the synergy between STEAM and the Merdeka Curriculum in a holistic manner. The findings are also anticipated to serve as a foundation for developing innovative, relevant, and contextual learning practices in primary education, as well as contributing to educational policy development in Indonesia.

METHODS

This study employed a Systematic Literature Review (SLR) approach to comprehensively examine the integration of the STEAM approach within the Merdeka Curriculum in primary education, focusing on publications from 2021 to 2025. The SLR method was selected because it enables the identification, selection, and synthesis of relevant literature to be conducted in a systematic, transparent, and replicable manner (Snyder, 2019). The review procedure followed the PRISMA 2020 framework to ensure traceability throughout the article selection process and to minimize potential bias in decision making (Page et al., 2021). The entire review process was conducted between February and March 2026, focusing on recent publications to capture the evolving implementation of STEAM in relation to the Merdeka Curriculum policy.

To guide the review process and ensure analytical focus, this study was structured around several research questions derived from the research objectives and identified gaps in the literature. The research questions are as follows:

Tabel 1. Research Questions

No	Research Question
1	How are the patterns of STEAM integration implemented in primary school learning based on the literature?
2	What instructional approaches and learning models are used to support STEAM implementation in primary education?
3	What impacts does the implementation of STEAM have on students' 21st century competencies?
4	How does the STEAM approach align with the principles of the Merdeka Curriculum in primary education?
5	What challenges are faced by teachers in implementing STEAM in primary school contexts?
6	What best practices can be identified to support effective STEAM implementation?

The literature search was conducted using several academic databases, including Google Scholar through the assistance of the Publish or Perish software, the Garuda Portal, Taylor and Francis Online, and Web of Science. The search strategy employed combinations of keywords using Boolean operators (AND, OR) as well as truncation techniques to broaden the scope of the search results. The primary keywords included "STEAM education" AND "elementary school", "STEAM integration" AND "primary education", "STEAM" AND "Merdeka Curriculum" OR "Kurikulum Merdeka", "curriculum reform" AND "STEAM", and "21st century skills" AND "primary school" AND "STEAM". To further refine the results within the Indonesian policy context, additional keywords such as "independent curriculum" and "Indonesian elementary school" were included. The search process was limited to articles published in English and Indonesian between 2021 and 2025 and included only peer-reviewed journal articles.

The initial identification stage yielded a total of 999 articles across all databases. After removing duplicate records, 718 articles remained. During the screening phase, titles and abstracts were reviewed to eliminate studies that were not relevant to the primary school context, did not explicitly discuss STEAM, or focused solely on STEM without integrating the arts component. This process resulted in 312 articles that proceeded to the full-text review stage. During the eligibility phase, the articles were evaluated based on their relevance to the focus of this study, particularly regarding the integration of STEAM in curriculum design, instructional implementation, or policy analysis related to the Merdeka Curriculum. Articles categorized as purely conceptual without empirical data, non-indexed conference proceedings, editorials, and studies conducted in secondary or higher education contexts were excluded from the analysis. Following the final selection process, a total of 15 articles met all inclusion criteria and were subsequently analyzed using qualitative synthesis. The overall selection procedure followed the recommended standards for systematic reporting to ensure transparency and replicability of the review process (Haddaway et al., 2022; Page et al., 2021). Furthermore, the inclusion and exclusion criteria, as well as the stages of article screening, are presented in the following section.

Table 2. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Empirical or systematic review articles discussing the implementation or integration of STEAM in primary education	Studies focusing on STEM without the integration of the Arts component
Publications from 2021–2025	Studies conducted at non-primary education levels without implications for elementary education
Studies situated within the context of national curriculum reform, educational policy, or the Merdeka Curriculum	Non-academic publications
Studies reporting impacts on 21st century competencies, learning outcomes, creativity, or the Pancasila Student Profile	Publications that have not undergone a peer-review process
Articles available in full text	Articles that are not available in full text

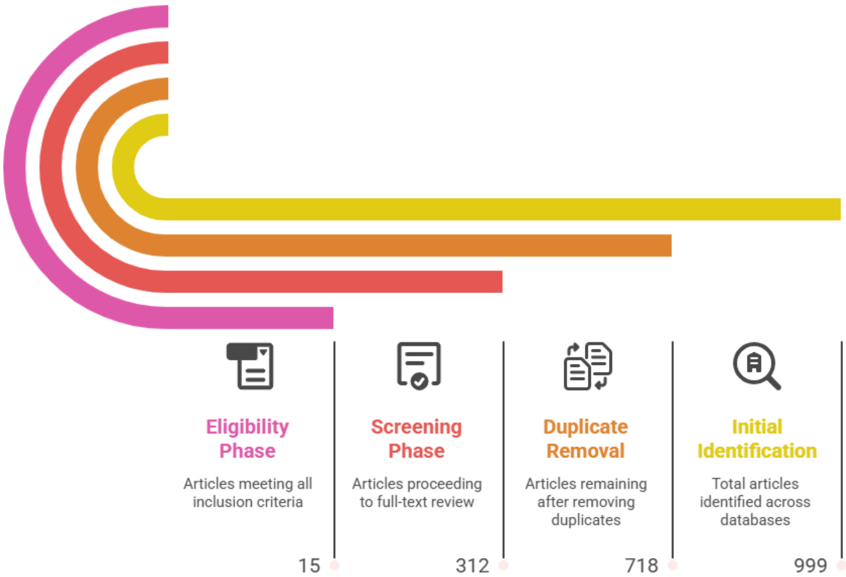

Figure 1. Article Screening Process

RESULTS AND DISCUSSION

The analysis included 15 articles published between 2021 - 2025 that examine the implementation of the STEAM approach within the Merdeka Curriculum, which has been applied across multiple educational levels in Indonesia. In this study, the analysis specifically focuses on its application in primary education. The fifteen articles that met the inclusion criteria are summarized in the following table.

Table 3. Data of Articles Meeting the Criteria

No	Title	Authors	Research Object
1	Enhancing the Science Literacy of Elementary School Students by a STEAM Approach (Juliyastuti et al., 2026)	Ika Anung Juliyastuti, Nanik Wijayati, Sri Sumartiningsih, dan Tri Joko Raharjo	Student
2	The Effect of STEAM Learning on Critical Thinking Skills of Elementary School Students (Zainil, Kenedi, et al., 2025)	Melva Zainil, Ari Kiswanto Kenedi, Asna Mardin, Refiona Andika, Dan Zuryanti	Student
3	Literacy skills through the use of digital STEAM-inquiry learning modules: A comparative study of urban and rural elementary schools in Indonesia (Susanta et al., 2025)	Agus Susanta, Edi Susanto, Rusnilawati, Hari Sumardi, dan Siti Rahmah Binti Ali	Student
4	STEAM-Project-Based Learning: A Catalyst for Elementary School Students' Scientific Literacy Skills (Suryanti et al., 2024)	Suryanti, Mochamad Nursalim, Nadia Lutfi Choirunnisa, Dan Ivo Yuliana	Student
5	Steam Learning in Elementary Schools: Implementation and Challenges (Nuragnia et al., 2021)	Berliany Nuragnia, Nadiroh, dan Herlina Usman	Teacher
6	Elementary School Teachers' Readiness to Integrate STEAM into Deep Learning. (Afifatin et al., 2025)	Trismalia Febrina Afiffatin, Inggit SaraswatiNur Ain, Shindy Aulia, dan Tia Citra Bayun	Teacher
7	The Effectiveness of the STEAM Approach on Critical Thinking Skills in Science and Scientific Attitudes in IPAS Learning in Primary Schools (Halimah et al., 2025)	Siti Halimah, Iik Nurulpaik, dan Encep Supriatna	Student
8	Steam-Based Science Module to Optimize Critical Thinking Skills of Grade V Elementary School Students (Sujaryanto et al., 2025)	Eko Sujaryanto, Sarwanto, dan Septi Yulisetiani	Student
9	The Effect Of Steam On Student Learning Activities In Elementary School (Rahayu et al., 2024)	Nina Rahayu, Febriyantika Wulandari, Dara Amanahtillah, dan Jelita	Student
10	Application of STEAM in PBL to Improve Creativity and Science Learning Outcomes: Case Study of	Muh. Rizal , Sri Muliani , Sarintan N Kaharu , Ijirana , Vivien Marvina , Elyas Djufri, dan Ika Kartika	Student

No	Title	Authors	Research Object
	Learning at SD Inpres Tanamodindi Palu (Rizal et al., 2025)		
11	Innovation in Steam Based Differentiation Learning Management (Harsono, 2025)	Arta Mulya Budi Harsono	Teacher
12	The Effect of Integrated STEAM-Based Smart Farming Implementation on Fourth-Grade Elementary School Students' Science Learning Outcomes. (Kartikawati, 2023)	Ariyanti Kartikawati, dan Farida Istianah	Student
13	Steam (Science Technology Engineering Art And Mathematics) Implementation And Challenges In Elementary Schools In West Java (Malagola, 2023)	Yopi Malagola	Teacher
14	Implementing Deep Learning STEAM to Improve Students' 4C Skills (Asmoni et al., 2026)	Asmoni Asmoni, Kurratul Aini, Mas'odi Mas'odi, dan Jihat Nurrahman	Student
15	STEAM-Based Deep Learning Training for Elementary School Teachers. (Zainil, Netrawati, et al., 2025)	Melva Zainil, Netrawati Netrawati, Arwin Arwin, Ary Kiswanto Kenedi, Dea Stivani Suherman, Asna Mardin	Teacher

The analysis of 15 articles indicates that the primary approaches used to integrate STEAM in elementary schools are Project-Based Learning (PjBL), Problem-Based Learning (PBL), and inquiry-based learning models. This finding is consistent with the study by (Suryanti et al., 2024), which states that project- and problem-based strategies are among the most effective ways to integrate the five STEAM disciplines meaningfully, while also enabling students to apply concepts through engineering processes, technology, and aesthetic considerations.

Furthermore, the results of (Kartikawati, 2023) reveal that STEAM integration encompasses three interconnected aspects, conceptual, procedural, and contextual dimensions that operate simultaneously, for example in thematic learning contexts such as Smart Farming. In addition, the study by (Susanta et al., 2025) explains that successful integration can also be achieved through the use of digital learning modules, collaborative activities among students, and reflective learning processes.

Quantitatively, the implementation of STEAM has shown a substantial influence on the development of competencies required in the twenty first century. The study conducted by Kenedi et al. (2025) indicates that the application of the STEAM approach significantly improves students' critical thinking skills because it provides project based learning experiences that encourage exploration and problem solving (Zainil, Kenedi, et al., 2025). Similarly, Halimah et al. (2025) report that the STEAM approach significantly enhances critical thinking abilities with a significance value of $p < 0.001$, while also fostering student creativity through processes of idea exploration and innovative product development (Halimah et al., 2025). In addition, the research conducted by Zainil, Netrawati et al. (2025) highlights that collaborative work and social interaction within STEAM learning environments strengthen students' communication and collaboration skills (Zainil, Netrawati, et al., 2025). Meanwhile, Juliyastuti et al. (2026) demonstrate that the implementation of STEAM learning improves students' understanding of scientific concepts, as reflected by the increase in the percentage of students achieving learning mastery up to 90.63 percent. These findings collectively indicate a consistent improvement in student competencies, particularly in the ability to connect theoretical concepts with real world contexts.

Furthermore, Sujaryanto et al. (2025) reveal that the STEAM approach is closely aligned with the principles of the Merdeka Curriculum because it encourages independent learning and supports the development of the Pancasila student profile through critical thinking and collaborative activities (Sujaryanto et al., 2025). Additional research by Harsono (2025) explains that differentiated learning based on the STEAM framework provides opportunities to adapt project activities according to students' interests, readiness levels, and learning needs (Harsono, 2025). However, Afifatin et al. (2025) indicate that the effective integration of STEAM still requires adequate technological support in order to fully align with the implementation of the national curriculum (Afifatin et al., 2025). These findings reinforce the argument that STEAM supports the implementation of the Merdeka Curriculum through contextual and project based learning that is relevant to students' experiences.

The readiness of teachers and the challenges encountered in implementing STEAM at the elementary school level are influenced by both pedagogical and technical factors. The study conducted by Nuragnia et al. (2021) shows that teachers still face several obstacles related to facilities, learning resources, and time allocation, even though collaborative learning approaches have been implemented (Nuragnia et al., 2021). Furthermore, Malagola (2023) explains that limitations in technology and instructional materials remain major challenges, particularly because the use of digital media within STEAM learning is still relatively limited (Malagola, 2023) . These findings emphasize the importance of continuous technical training and professional development programs to strengthen teachers' capacity in implementing STEAM effectively in elementary school settings.

STEAM Integration Patterns in Elementary School Learning

Based on the synthesis of 15 analyzed articles, the implementation of the STEAM approach in elementary schools demonstrates a consistent, systematic, and progressive pattern of integration. This pattern can be understood as a hierarchical framework that moves from philosophical foundations to practical instructional applications, as illustrated in Figure 3. The integration begins with a constructivist approach as the primary foundation, develops into student-centered learning, and is ultimately realized through the implementation of project-based, problem-based, and inquiry-based learning models.

At the foundational level, STEAM learning is grounded in constructivist principles, which emphasize that learners actively construct knowledge through meaningful learning experiences. From this perspective, knowledge is not directly transmitted from teacher to students; rather, it is developed through interaction with the environment, reflective processes, and active engagement in learning activities. This approach is further strengthened by the principles of student-centered learning, where instruction is designed to accommodate students' needs, interests, and individual characteristics. Consequently, students act as active agents in the learning process, while teachers function as facilitators who guide exploration and discovery.

Furthermore, the implementation of STEAM is operationalized through three complementary instructional models. Project-Based Learning (PjBL) is employed to encourage students to learn through meaningful and contextualized projects. Through this approach, students not only understand theoretical concepts but are also able to apply them in the creation of tangible products. Research by Suryanti et al. (2024) indicates that the application of PjBL within STEAM significantly improves students' scientific literacy compared to conventional approaches. This improvement is attributed to students' active involvement in the planning, implementation, and evaluation stages of the project.

In addition, Problem-Based Learning (PBL) plays a crucial role in developing critical thinking and problem-solving skills. In this model, students are confronted with real-world problems relevant to their daily lives, encouraging them to analyze, evaluate, and formulate solutions both independently and collaboratively. Similar findings were reported by Rizal et al. (2025), who found that the integration of STEAM through PBL gradually enhances students' creativity and science learning outcomes across instructional cycles. This suggests that problem-based learning impacts not only cognitive aspects but also higher-order thinking skills.

At a more exploratory level, Inquiry-Based Learning (IBL) strengthens the process of independent knowledge construction. Through this approach, students are encouraged to pose questions, conduct investigations, and discover concepts through scientific processes. Susanta et al. (2025) found that the use of STEAM-based digital modules with an inquiry approach significantly improves students' mathematical literacy. The processes of investigation, experimentation, and reflection embedded in inquiry-based learning provide deep and meaningful learning experiences. These findings support previous studies by Nuragnia et al.

(2021) and Malagola (2023), which emphasize that STEAM implementation in elementary education commonly integrates inquiry approaches, problem-based learning, and collaborative, student-centered activities.

Moreover, the integration pattern of STEAM is not only reflected in the instructional models employed but also in the form of interdisciplinary integration. This includes conceptual, procedural, and contextual integration. Conceptual integration combines knowledge from science, technology, engineering, arts, and mathematics into a unified learning theme. Procedural integration emphasizes the use of scientific thinking processes and engineering design in solving problems. Meanwhile, contextual integration connects learning to real-life situations within students' environments, thereby enhancing the relevance and meaningfulness of the learning experience.

Overall, the characteristics of learning emerging from STEAM implementation indicate a paradigm shift from traditional instruction toward more active, collaborative, and experiential learning. Activities such as group discussions, project exploration, presentations, and reflective practices become central components of the learning process. In addition, STEAM learning provides opportunities for the development of 21st-century skills, including critical thinking, creativity, communication, and collaboration.

In conclusion, the integration pattern of STEAM forms a systematic and comprehensive framework, beginning with constructivist foundations, oriented toward student-centered learning, and implemented through PjBL, PBL, and IBL models. This pattern not only enhances conceptual understanding but also improves the overall quality of learning in elementary schools across cognitive, affective, and skill-based domains.

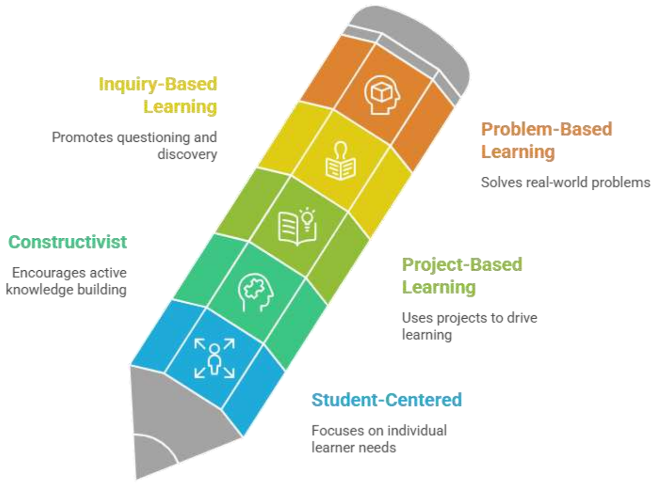

Figure 2. STEAM Integration Patterns in Elementary School Learning

The Impact of STEAM Implementation on 21st-Century Competencies

The implementation of the Science, Technology, Engineering, Arts, and Mathematics (STEAM) approach at the elementary school level has been shown to make a significant contribution to strengthening 21st-century competencies. Visually, these impacts can be mapped into four main pillars, as illustrated in Figure 3.

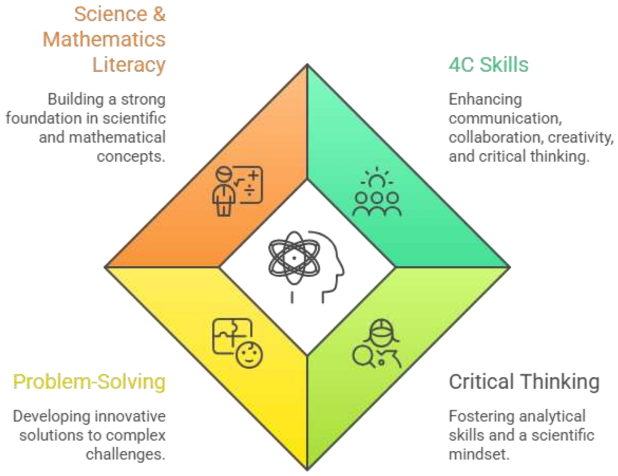

Figure 3. The Impact of STEAM Implementation on 21st-Century Competencies

Based on the figure 3, within the dimension of *Science and Mathematics Literacy*, the STEAM approach plays a strategic role in building a strong conceptual foundation through interdisciplinary integration. This approach enables students to understand the relationship between scientific and mathematical concepts in a more contextualized manner. Findings from Juliyastuti et al. (2026) indicate a progressive improvement in students' scientific literacy, marked by an increase in the passing rate from 43.75% at the initial stage to 90.63% at the end of the cycle. These results are consistent with Susanta et al. (2025), who found that the use of inquiry-based STEAM digital modules significantly enhances mathematical literacy, particularly in helping students transform abstract concepts into more applicable and meaningful understanding.

Furthermore, in the *4C Skills* pillar comprising communication, collaboration, creativity, and critical thinking the implementation of STEAM demonstrates simultaneous and mutually reinforcing improvements. Asmoni et al. (2026) reported that the application of a STEAM-based deep learning model increased the average score of students' 4C skills from 47.19 in the pretest to 81.67 in the posttest. This improvement is closely linked to the integration of the *Arts* component, which, according to Rahayu et al. (2024), significantly enhances students' emotional engagement and learning activity while encouraging creative exploration of ideas.

In terms of *critical thinking*, the STEAM approach consistently contributes to the development of analytical sharpness and scientific attitudes among students.

Zainil, Kenedi, et al. (2025) found that students in the STEAM group achieved an average post-test score of 82.90, significantly outperforming the control group, which scored 61.20. Additionally, Halimah et al. (2025) reported that the STEAM approach accounts for 19.3% of the variance in students' critical thinking skills. The availability of well-structured instructional materials, such as STEAM-based IPAS modules (Sujaryanto et al., 2025), has also proven crucial in facilitating deeper, more systematic, and reflective thinking processes.

Finally, in the *problem-solving* pillar, STEAM serves as the integrative culmination of all developed competencies. Through this approach, students are not only expected to understand concepts but also to formulate innovative solutions to complex real-world problems. Rizal et al. (2025) reported that the implementation of STEAM within a problem-based learning model improved students' science problem-solving abilities from a "moderate" to a "very good" category.

Overall, the interconnection among the four pillars in the diagram highlights that the STEAM approach represents a comprehensive and consistent instructional framework for accelerating the development of 21st-century competencies. The integration of science and mathematics literacy, the strengthening of 4C skills, the enhancement of critical thinking, and the improvement of problem-solving abilities demonstrate that STEAM is not only conceptually relevant but also empirically effective in the context of elementary education.

The Relevance of STEAM to the Principles of the Merdeka Curriculum

The literature synthesis indicates that the STEAM approach not only aligns with, but also strengthens the implementation of key principles within the *Merdeka Curriculum*. This integration forms an interconnected conceptual framework that contributes to more contextual, meaningful, and competency-oriented learning, particularly in fostering 21st-century skills. The relationships among these principles are illustrated in Figure 4.

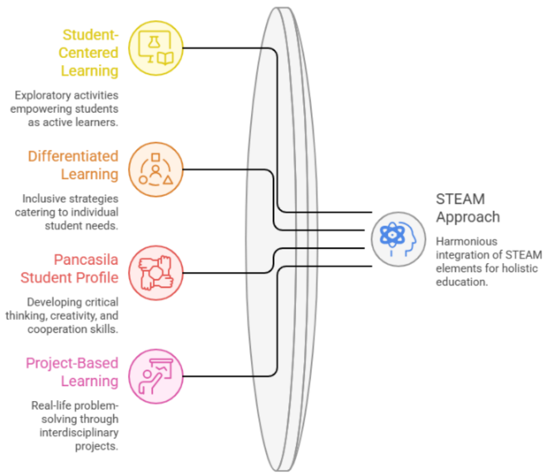

Figure 4. The Relevance of STEAM to the Principles of the Merdeka Curriculum

Based on the figure, the STEAM approach demonstrates strong conceptual alignment with the learning principles of the *Merdeka Curriculum*, particularly in promoting a shift from transmissive to constructive and participatory learning. The principle of student-centered learning requires active student engagement in the construction of knowledge. In this context, STEAM not only accommodates this principle but also operationalizes it through exploratory activities, experimentation, and collaborative projects that position students as the central actors in the learning process (Wardani et al., 2025).

Furthermore, the implementation of differentiated learning within the *Merdeka Curriculum* finds strong relevance in the flexible and adaptive nature of the STEAM approach. STEAM enables variation in learning processes, products, and content, allowing teachers to tailor instructional strategies to students' diverse needs and characteristics. However, the effectiveness of STEAM-based differentiation is highly dependent on teachers' pedagogical competence in designing responsive instruction. This suggests that although there is strong conceptual alignment, practical implementation still faces challenges, particularly in relation to teacher readiness and resource availability (Harsono, 2025).

From the perspective of strengthening the *Pancasila Student Profile*, the STEAM approach inherently supports the development of key 21st-century competencies, such as critical thinking, creativity, and collaboration. Project-based activities within STEAM encourage social interaction, teamwork, and the exchange of ideas among students. Nevertheless, several studies indicate that affective dimensions and value-based components are not always explicitly integrated into STEAM instructional design. Therefore, more systematic planning is required to ensure that the values embedded in the *Pancasila Student Profile* are intentionally incorporated, rather than emerging merely as indirect outcomes (Asmoni et al., 2026).

Structurally, the alignment between STEAM and Project-Based Learning (PjBL) represents a key factor in supporting the implementation of the *Merdeka Curriculum*. Through contextualized projects, students are able to integrate multiple disciplines in solving real-world problems. However, the dominance of project-based approaches in STEAM implementation may also present limitations if not complemented by other approaches, such as deep inquiry and conceptual reflection, which are essential for strengthening students' theoretical understanding.

In conclusion, STEAM is not only relevant but also holds strong potential as a strategic approach for actualizing the principles of the *Merdeka Curriculum*. However, its successful implementation is highly contingent upon teacher readiness, the quality of instructional design, and comprehensive support from the education system. Therefore, the integration of STEAM should be viewed as part of a broader pedagogical transformation, rather than merely as an instructional innovation.

Teacher Readiness and Challenges in Implementing STEAM in Elementary Schools

Although the STEAM approach demonstrates numerous benefits in elementary school learning, several studies also highlight various challenges encountered in its implementation. One of the primary factors influencing the successful application of STEAM is teachers' pedagogical readiness in understanding the integrative nature of the approach. The study conducted by Afifatin et al. (2025) indicates that most teachers possess strong motivation to implement STEAM based learning; however, they still experience difficulties in mastering the integrative concepts underlying the approach as well as in utilizing supporting technologies within the instructional process (Afifatin et al., 2025).

In addition, several studies identify a range of technical constraints that hinder the effective implementation of STEAM. Research by Nuragnia et al. (2021) reveals that major challenges include limited facilities, a lack of relevant learning resources, and insufficient time allocation for project based learning activities (Nuragnia et al., 2021). Similar findings are reported by Malagola (2023), who notes that barriers to STEAM implementation in elementary schools involve limited technological infrastructure, inadequate learning facilities, and a lack of teacher training related to strategies for integrating STEAM into classroom instruction (Malagola, 2023).

Beyond infrastructural and pedagogical issues, the complexity of instructional planning also presents a challenge for teachers. STEAM based learning generally requires more comprehensive project planning, more complex coordination of learning activities, and the use of assessment methods capable of evaluating multiple dimensions of student competence simultaneously. Consequently, continuous professional development programs are essential to support teachers in implementing STEAM effectively in elementary school contexts.

Efforts to strengthen teacher capacity through training have also shown positive outcomes. The study conducted by Zainil, Netrawati, et al. (2025) on STEAM based deep learning training demonstrates that such programs significantly improve teachers' abilities to design interdisciplinary learning experiences aligned with the national curriculum (Zainil, Netrawati, et al., 2025). This finding suggests that the availability of structured training programs, teacher learning communities, and adequate instructional resources are crucial factors in optimizing the implementation of STEAM in elementary education.

CONCLUSION

Based on the systematic literature review of 15 selected articles, this study reveals that the integration patterns of the STEAM approach in primary education are constructed systematically through a constructivist foundation oriented toward student-centered learning and operationalized through Project-Based Learning

(PjBL), Problem-Based Learning (PBL), and inquiry-based learning models. These models serve as the primary instructional approaches in supporting contextual and interdisciplinary STEAM implementation. Empirically, the implementation of STEAM demonstrates a significant impact on the development of students' 21st century competencies, particularly in critical thinking, creativity, communication, and collaboration, as well as in strengthening science literacy and problem-solving skills. Furthermore, the STEAM approach shows strong alignment with the principles of the Merdeka Curriculum, especially in promoting independent learning, differentiated instruction, and the reinforcement of the Pancasila Student Profile through meaningful and contextually relevant learning experiences.

However, despite its strong potential, the implementation of STEAM still faces several challenges, particularly related to teachers' pedagogical readiness, limitations in technological facilities, and the complexity of designing project-based learning. These findings indicate that the successful integration of STEAM depends not only on conceptual alignment but also on systemic educational support. The identified best practices include the use of STEAM-based digital learning modules, the implementation of collaborative learning activities, and continuous professional development programs for teachers. Therefore, strengthening teacher capacity and improving technological infrastructure are essential factors in optimizing the integration of STEAM within the Merdeka Curriculum, ensuring that this synergy can be implemented more effectively, sustainably, and with broader impacts on the quality of primary education.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

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