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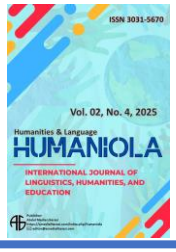

Implementation of Digital Technology-Based STEM Approach in Elementary Schools: A Systematic Literature Review

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ABSTRACT

The advancement of digital technology has driven a transformation in elementary education toward more interactive and collaborative learning aligned with 21st-century competencies. This study conducts a systematic literature review of publications from 2020 to 2025 to map the implementation of digital-based STEM in elementary schools, the learning models employed, the impacts on student outcomes, and the challenges encountered. Article searches were conducted in Google Scholar and the SINTA-indexed database, following the PRISMA 2020 guidelines, yielding 10 studies for thematic analysis. The review indicates the use of interactive e-modules, digital videos, learning applications, virtual laboratories, and educational robotics, which generally enhance learning outcomes, creativity, numeracy literacy, critical thinking, and computational thinking. Key challenges include limited infrastructure, teacher readiness, and inconsistent quality of digital media. The findings underscore the need for policy support, improved teacher competencies, and higher-quality digital learning resources to optimize the integration of digital-based STEM in elementary education.

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1. Introduction

The development of digital technology and the demands of 21st-century competencies have prompted the education world to shift its focus from content-based learning to the development of digital literacy, critical thinking, and problem-solving skills. The STEM (Science, Technology, Engineering, Mathematics) approach has become a relevant learning approach because it integrates several disciplines through contextual, student-centered activities. Recent research in elementary schools shows that STEM-based science instruction can significantly improve 21st-century skills (Yuliasari, 2024). This aligns with the findings of Li et al. (2020), which confirm that STEM integration in elementary education can strengthen the foundations of science and engineering literacy while fostering student interest in technology.

Advances in digital technology have expanded the scope of STEM implementation through the use of digital media such as interactive e-modules, learning applications, science simulations, and simple robotics devices. A recent international literature review

by García-Holgado et al. (2020) shows that digital technology plays an important role in increasing student motivation and access to richer STEM experiences. These findings are in line with a national study that reports that the integration of ICT in basic education can improve the quality of the learning process if teachers receive adequate training and pedagogical guidance (Syahrir et al., 2024).

Although digital technology has the potential to strengthen STEM learning, its implementation in elementary schools often faces challenges. Teachers' limited competence in designing digital learning experiences, uneven infrastructure availability, and variations in the quality of digital learning media are common obstacles. For example, research on the development of STEM-based digital media shows that the effectiveness of the media is highly dependent on the ability of teachers to facilitate the use of this technology (Kurnia et al., 2025). In addition, a meta-analysis by Tsai et al. (2023) confirms that the successful integration of technology into STEM learning is strongly influenced by instructional design and support for the learning environment, rather than just device availability.

Another issue that arises is the lack of long-term research related to the implementation of digital STEM, both in the context of changes in learning behavior and its impact on the development of cross-disciplinary competencies. Many studies at the elementary level are still single cases, short-term, or lack strong comparisons, making them difficult to generalize. This is emphasized by Hinojo-Lucena et al. (2021), who state that digital STEM research at the elementary education level still requires a more rigorous methodological approach to obtain a comprehensive and reliable picture of its implementation.

Considering these needs, a systematic literature review is required to compile and analyze the latest research findings on the implementation of digital technology-based STEM approaches in elementary schools. This review aims to map the types of technology used, the learning models applied, the impact on learning outcomes, and the implementation challenges faced. The results are expected to contribute to the development of policies, learning practices, and research that are more relevant to the dynamics of digital education today.

2. Method

This study applies a systematic literature review approach based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses **(**PRISMA 2020**)** guidelines to produce a systematic and accountable scientific synthesis of the implementation of the digital technology-based STEM approach at the elementary school level. The article search process was conducted through two main databases, namely Google Scholar and the SINTA indexed publication portal, with a publication range of 2020–2025 to ensure the recency of the findings. The keywords used included "STEM," "digital technology," "elementary school," and similar terms in Indonesian and English. The articles found were then selected based on the following inclusion criteria: (1) empirical research or conceptual studies discussing the implementation of digital technology-based STEM at the elementary school level, (2) available in full access, and (3) published in reputable journals. The exclusion criteria included articles that were not relevant to the context of primary education, did not explicitly use digital technology in STEM implementation, or were only abstracts without complete data.

After the initial screening process, selected articles were analyzed thematically to identify patterns of digital technology use, applied STEM learning models, the impact of implementation on student learning outcomes, and reported challenges. The analysis

was conducted through the stages of initial data labeling, categorization, and synthesis of findings, using a narrative approach. The validity of the review process was maintained by applying source triangulation and checking the consistency of themes between studies. Each article was reviewed independently to ensure objectivity of interpretation, and the findings were then integrated into a comprehensive mapping framework. This procedure enabled the study to produce a systematic overview of trends, effectiveness, and barriers to the implementation of technology-based STEM in elementary schools.

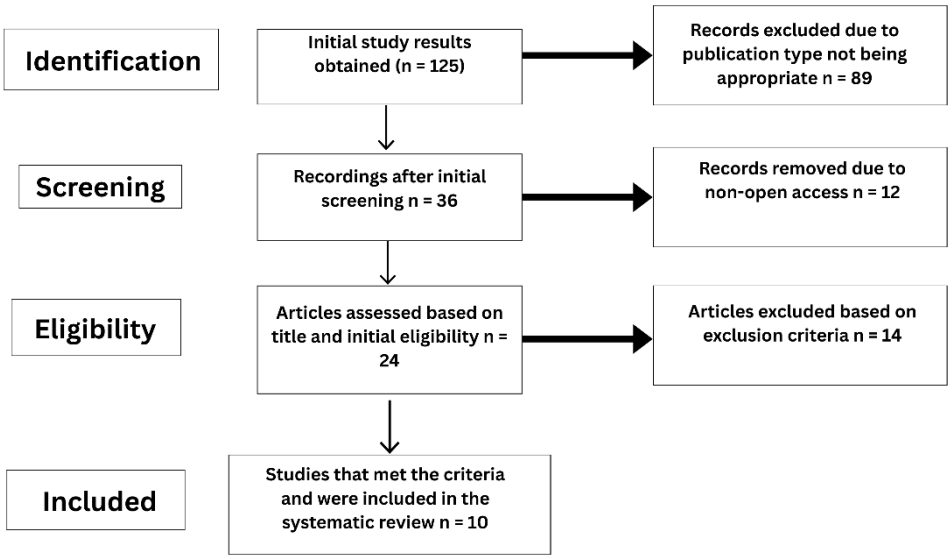

Figure 1. Diagram of Search Terms and Publication Selection Process (PRISMA Flowchart)

3. Result and discussion

This section presents the research results and discussion obtained from a systematic literature review of ten selected articles. The analysis was conducted to describe how the digital technology-based STEM approach is implemented in elementary schools, the types of technology used, and its impact on learning. In addition, this section highlights the challenges reported in implementing digital STEM. The findings presented are expected to provide a comprehensive overview of trends, effectiveness, and important issues in the integration of digital technology in STEM learning in primary education.

Table 1. Implementation of digital technology-based STEM in elementary schools

No	Titles and Authors	Digital Technology	Key Findings and Results
1	*Pengembangan E-Modul Berbasis STEM untuk Meningkatkan Keterampilan Berpikir Kreatif Peserta Didik dalam Pembelajaran IPA di Sekolah Dasar* Penulis: Siti Rofikoh, Supeno & Farisi (2022)	STEM-based digital E-modules	E-modules are valid and practical; they improve students' creative thinking in science.

2	*Implementasi Model Pembelajaran STEM dalam Pembelajaran Matematika di SD* Penulis: Welli Meinarni (2023)	Project-based learning/simple technology (basic technology and STEM-based activities)	Students are able to create simple technology and demonstrate the implementation of STEM in mathematics at the elementary level.
3	*Implementasi Pendekatan STEM Berbantuan Media Pembelajaran Interaktif Vlog di Sekolah Dasar* Erpin Rahayu, Irwan Akib, Rukli & M. Ilham S. (2023)	Interactive vlog-based learning media	Students' maths pretest and posttest scores improved significantly after implementing STEM with interactive digital media.
4	*Primary School STEM Education Innovation through ICT Integration for Teacher Competency Development: A Systematic Literature Review* Syahrir, Pujiriyanto, Musdalifa As, Fahrul A. M. Nur & Fitri (2024)	Integrating ICT in STEM at the primary school level.	The practical implementation of ICT-STEM contributes to advancing teachers' competencies and improving STEM learning processes at the elementary level.
5	*Integrated STEM-based Teaching Modules with the Values of Pancasila Student Profiles in Supporting the Implementation of Kurikulum Merdeka in Primary School* Fina Nur Oktaviah, Anik Dwiyanti, Suyadi & Barumbun (2022)	STEM teaching module that incorporates character development, technology, and contextualized learning.	Modules are suitable for use; student learning outcomes have improved; student and teacher responses are positive.
6	*Pengembangan Modul Ajar Berbasis STEM untuk Mewujudkan Kreativitas pada Siswa Fase B Sekolah Dasar* Elsa Eri Asmara, Siti Patonah & Sukamto (2023)	IPAS teaching modules, STEM, and creativity	The STEM modules have been proven valid, practical, and effective in enhancing students' creativity at the elementary level.
7	*Efektivitas Penggunaan Model Pembelajaran STEM terhadap Literasi Numerasi Siswa SD* Vivi Rulviana, Rissa P. Kurniawati & Dian P. Kusuma Dayu (2024)	STEM Teaching Model (Integrating the STEM approach in mathematics)	The STEM modules have been proven valid, practical, and effective in improving students' numeracy literacy at the elementary level

8	*The Influence of Educational Robotics in STEM Integrated Learning and the Development of Computational Thinking Abilities* Muhammad Aqil Sadik, Cucuk W. Budiyanto & Rosihan A. Yuana (2024)	Educational robotics	The use of robotics improves students' computational skills and supports STEM-integrated learning.
9	*The effects of educational robotics in STEM education: a multilevel meta-analysis* Fan Ouyang & Weiqi Xu (2024)	Educational robotics as part of STEM	In general, the use of robotics in STEM has a positive effect on students' engagement in learning activities and their learning outcomes at various levels.
10	*Implementasi Pembelajaran STEM terhadap Keterampilan Berpikir Kritis Siswa Sekolah Dasar* Vitra Nailinda, Jesi A. Alim & Mestika Sekarwinahyu (2025)	Conventional STEM learning and integrating STEM.	The experimental class showed a significant improvement in critical thinking skills compared to the control class.

A systematic literature review of 10 articles published between 2020 and 2025 shows that the implementation of technology-based STEM in elementary schools has grown rapidly, particularly in science, mathematics, educational robotics, interactive digital media, and STEM-based e-modules. The development of digital technology—ranging from interactive e-modules, educational vlogs, LMS, virtual labs, to robotics—has encouraged the emergence of more contextual, interactive, and student-centered learning innovations. Most of the studies in this SLR report improvements in student learning outcomes, creativity, computational thinking, numeracy literacy, and critical thinking after the integration of STEM and digital technology. However, various implementation challenges remain, such as limited devices, teacher readiness, and the need for appropriate instructional design.

3.1. Forms and Types of Digital Technology in the Implementation of STEM in Elementary Schools

A review of the literature shows that the use of digital technology in the context of STEM learning in elementary schools includes various forms, ranging from interactive e-modules, vlog-based digital videos, digital learning applications and platforms, virtual laboratories, to educational robotics. These technologies not only serve as a medium for delivering content, but also as a means of exploring science and mathematics concepts through a more dynamic learning experience.

Various development studies (Rofikoh et al., 2022; Oktaviah et al., 2022; Asmara et al., 2023) prove that STEM-based digital teaching modules have a high level of validity and practicality and are capable of supporting thematic and contextual learning. Meanwhile, research on educational robotics (Sadik et al., 2024; Ouyang & Xu, 2024)

shows that robotic devices can enrich STEM practices through problem-solving and simple engineering activities.

Overall, the diversity of digital technologies used reflects the expansion of the spectrum of STEM implementation towards more exploratory, interactive, and experience-oriented learning, enabling students to construct abstract concepts more concretely.

3.2. The Implementation of Digital Technology-Based STEM Learning Models and Their Impact on Learning Outcomes

Based on SLR findings, the implementation of digital technology-based STEM in primary education generally adopts a project-based STEM approach, a problem-based STEM approach, and STEM integration within context-based and technology-based teaching modules. The learning design implemented positions students as active subjects in the exploration, design, and problem-solving processes.

All articles in this review consistently report positive impacts on various dimensions of student learning outcomes. The use of interactive e-modules and vlog media increases creativity, learning motivation, and understanding of science and mathematics concepts (Rahayu et al., 2023; Rofikoh et al., 2022). Robotics learning contributes significantly to the development of computational thinking and problem-solving skills (Sadik et al., 2024). Meanwhile, the application of the STEM model in mathematics has been shown to be effective in improving numeracy literacy (Rulviana et al., 2024).

These findings emphasize that integrating digital technology not only enriches the representation of concepts but also increases students' cognitive, affective, and psychomotor engagement in the learning process. Thus, digital technology acts as a facilitator that strengthens the effectiveness of STEM instructional design.

3.3. Challenges in Implementing Digital Technology-Based STEM and Factors Determining Effectiveness

Although the implementation of STEM education based on digital technology provides substantial benefits, a number of obstacles remain in practice in elementary schools. The main challenges include:

1. Limitations in infrastructure and technological devices, especially in schools with unequal digital access.
2. Variability in teacher competence, particularly in designing, modifying, and facilitating STEM learning through digital media.
3. Inconsistent quality of digital learning media undermines the effectiveness of the learning process.
4. A lack of continuous professional training and development is necessary to fully understand the STEM approach.

These findings align with the studies by Tsai et al. (2023) and Syahrir et al. (2024), which emphasize that the success of technology integration depends not only on device availability but also on the suitability of instructional design, teacher readiness, and support for the learning environment. Thus, the effectiveness of digital technology-based STEM implementation will be optimal if accompanied by strengthening teachers' pedagogical capacity, developing quality digital media, and providing adequate infrastructure.

A more in-depth discussion of the implementation of technology-based STEM shows that the program's success is greatly influenced by the readiness of the broader

education ecosystem. One strategic issue that needs further exploration is how teachers' roles as facilitators change in digital learning contexts, particularly in classroom management, instructional adaptation, and assessment of student learning.

In addition, the need for long-term research is increasingly urgent, as most studies remain short-term and focus on immediate learning outcomes. Longitudinal studies can provide an overview of the impact of digital STEM on the development of interdisciplinary skills, long-term learning motivation, and student interest in science and technology.

Another important aspect to discuss is the digital divide between schools. Although some studies show positive results, effective implementation cannot be achieved evenly without adequate infrastructure support. Therefore, the successful implementation of digital STEM requires a systemic approach that includes funding policies, professional development, the development of educational technology, and multi-stakeholder collaboration.

4. Conclusion

A systematic literature review of 10 publications from 2020–2025 shows that the implementation of digital technology-based STEM approaches in elementary schools has advanced significantly and contributed positively to learning quality. Various forms of digital technology—ranging from interactive e-modules and digital video media to learning platforms and educational robotics—consistently strengthen student engagement and support the development of 21st-century competencies. Digital technology-based STEM learning models have been proven effective in improving creativity, critical thinking, numeracy literacy, computational thinking, and students' conceptual learning outcomes.

However, the implementation of digital STEM still faces challenges, particularly related to infrastructure limitations, teachers' pedagogical readiness, varying quality of digital media, and a lack of systemic support in technology-based learning management. Therefore, the success of implementation depends not only on the technology used but also on instructional design, teacher capacity, and institutional support.

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