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The role of STEM-based learning media in improving students' science literacy: A systematic review

Tina Oktasari, Sardianto Markos Siahaan *, **Leni Marlina**
Universitas Sriwijaya, Indonesia.
* Corresponding Author. E-mail: mr.sardi@unsri.ac.id

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ABSTRACT

In the 21st century, scientific literacy is an essential skill for students, but many challenges remain in learning it. To address these challenges, integrating STEM-based learning media offers an innovative solution by promoting contextual, interactive, and project-based learning that enhances students' engagement, critical thinking, and understanding of scientific concepts. This study aims to systematically review the role of STEM-based learning media in improving students' science literacy, identify the characteristics of effective media, and the factors that influence their successful implementation. This study used a systematic review method following PRISMA guidelines, analysing 21 selected articles from Google Scholar, Web of Science, DOAJ, and ERIC databases, with a publication range of 2019-2025. The analysis shows that STEM-based media effectively improve students' understanding of science concepts, critical thinking skills, and digital literacy. Interactive, project-based and contextualised media proved most effective. The main supporting factors for successful implementation include teacher competence, valid and practical media design, and support for the learning environment. This study emphasises the importance of integrating STEM-based learning media to improve overall science literacy. Future research is recommended to explore the long-term impact of STEM-based learning media on students' science literacy across diverse educational levels and cultural contexts, and to develop adaptive digital tools that support personalised learning and teacher facilitation.

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INTRODUCTION

In the face of the dynamics of the 21st century, science literacy is a fundamental need for every individual to participate in a knowledge- and technology-based society actively. Science literacy is not only the ability to understand scientific concepts, but also encompasses critical thinking, problem-solving, and evidence-informed decision-making in daily life (Falloon et al., 2020). The results of national and international studies show that students often have difficulty in understanding scientific concepts as a whole and linking them to real-world contexts. This is inseparable from the various challenges in the science learning process in schools, such as low student interest in science, abstract and theoretical learning content, and less innovative, teacher-centred learning approaches (Santos et al., 2023). The lack of meaningful, applicable learning experiences prevents students from developing scientific thinking skills effectively (Aini et al., 2020).

STEM education is a learning innovation that equips students with the skills needed in the 21st century. The STEM-based learning approach (Science, Technology, Engineering, and Mathematics) emerged as an innovative alternative to address the challenges of current science education (Karimah & Wulandari, 2023). Implementing STEM education in learning activities can encourage students to use technology to design, develop, and improve cognitive processes and to apply knowledge (Wahono et al., 2023). The STEM approach integrates the four main disciplines harmoniously, emphasising the solution of real problems through project-based activities and exploration (Sole, 2021). STEM learning emphasises collaboration, creativity, and critical and reflective thinking, all of which support the holistic development of students' science literacy (Harpian et al., 2023). With this approach, learners not only learn science conceptually, but also apply it practically in real-life situations (Setiawan, 2019).

Numerous studies indicate that using STEM-focused learning resources can significantly enhance students' science literacy across different educational levels. For example, the use of e-modules integrating Sustainable Development Goals (SDGs) principles has been shown not only to improve understanding of science concepts but also to foster students' environmentally friendly attitudes and social care (Aswirna et al., 2022). Meanwhile, the development of worksheets based on STEM and local wisdom has also been shown to be content valid and effective in improving students' scientific literacy skills in specific topics, such as thermal energy (Ariefianti et al., 2023). The STEM approach has proven relevant to apply from the primary education level and even pre-school. Research shows that children exposed to early STEM learning show significant improvements in science and visual literacy, and have better scientific communication skills (Ramulumo, 2024). This aligns with findings that STEM learning, when delivered through integrated projects or modules, can be an effective means of developing students' scientific literacy and critical thinking skills from an early age (Aguilera & Ortiz-Revilla, 2021).

Numerous research efforts have demonstrated the benefits of STEM-based learning media in improving science literacy. However, there is no systematic study that comprehensively reviews the various forms of such media, their characteristics, and the effectiveness of their implementation in various educational contexts. Consequently, this research intends to conduct a systematic review of the existing literature on the functions of STEM-oriented learning resources and their impact on enhancing students' scientific literacy across different educational levels. Specifically, this review seeks to examine how STEM-based learning media improve students’ science literacy, identify the characteristics of effective STEM-based learning media in science education, and analyse the key factors that influence the successful implementation of these learning resources in educational institutions. The findings of this study are expected to provide educators, curriculum developers, and policymakers with valuable insights for designing and implementing more effective, engaging, and contextually relevant STEM-based learning strategies to improve science literacy outcomes.

METHOD

This study applied the systematic literature review approach as done by (Ashiq et al., 2022) to critically appraise the published literature on STEM, implementation models, benefits, challenges, impacts, and practical recommendations that can be applied by educators who want to integrate STEM in teaching practices, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards. The PRISMA guidelines allow researchers to methodically document evidence-based elements that are useful for thoroughly assessing published literature, as highlighted (Moher et al., 2009; Ashiq et al., 2022). PRISMA considers four elements of a study, namely identification, screening, eligibility, and included studies. PRISMA was initially created for the healthcare sector but has proven relevant across numerous other domains. Furthermore, we utilised the PRISMA 2020 Checklist to structure the study title, objectives, methods, results, discussion, and other specifics (primarily concentrating on search details, inclusion and exclusion criteria, synthesis of results, risk of bias, etc.) (Yepes-Nuñez et al., 2021).

Search Strategy

Data for this study were collected through keyword searches across four major online academic search engines: Google Scholar, Web of Science (WOS), Directory of Open Access Journals (DOAJ), and Education Resources Information Centre (ERIC). Keywords were selected based on their relevance to STEM, learning media and science literacy. To progress to the next stage, each article had to include "STEM" or information about learning media platforms and at least one other keyword in the title or abstract. The author ran the following search on April 29, 2025. The keywords and search operators used were ("STEM-based learning media") AND ("Science literacy" OR "Scientific literacy") AND ("Students" OR "Learners") AND ("STEM education" OR "Integrated learning approach").

Inclusion and Exclusion Criteria

We incorporated all pertinent studies released from 2019 to 2025 regarding STEM-oriented learning resources. Only original peer-reviewed research articles were considered, along with studies that focused on multiple aspects of the study or accomplished at least two research goals. Included research studies include STEM implementation models, benefits, challenges and impacts encountered in the application of STEM-oriented educational resources. In addition, only English and Indonesian research articles were included. As shown in Table 1. Inclusion and exclusion criteria.

Table 1. Inclusion and Exclusion Criteria

No.	Inclusion Criteria	Exclusion Criteria
1	Articles with publication year range: 2019-2025	Published before 2019
2	Original research or systematic reviews that examine STEM-focused educational media in elementary, middle, high school, or university education settings	Studies that are unrelated to the topic of utilising STEM-focused learning resources in elementary, middle, high school, or university education
3	Article in English or Indonesian and available in full text	Written in languages other than Indonesian and English, and not available in full text
4	Articles that include the official DOI	Unreliable sources, such as personal blogs or social media, without scientific references

The identification stage involved collecting scientific articles from four central databases: Google Scholar, Web of Science (WOS), Directory of Open Access Journals (DOAJ), and Educational Resources Information Centre (ERIC). From this process, we collected 245 articles that used the keywords "STEM-based learning media" and "Science literacy" or "Scientific literacy" in their titles or abstracts. Next, we proceeded to the screening stage by removing duplicate articles, leaving 190. Then, an initial selection was made by removing articles that did not meet the criteria, such as those with inappropriate language (not in Indonesian or English) and those not at the primary, middle school, secondary school, or college levels. A total of 97 articles were eliminated at this stage, leaving 93 articles for further analysis.

Then, the eligibility stage was conducted by assessing the availability of the full texts of the articles. Twenty-five articles were removed since they were not accessible in their complete form. Out of the 68 articles left, a comprehensive examination of the material was performed. At this stage, 47 articles were excluded because they only discussed one narrow aspect, such as STEM implementation models, benefits or challenges without empirical data, and did not directly assess the influence of STEM-focused educational materials on students' scientific understanding. Finally, the inclusion phase yielded 21 articles that satisfied all the inclusion criteria and served as the primary data source for this study. The articles were then analysed to answer three research questions: the effects of STEM-based learning media, their characteristics, and the factors that affect the effective implementation of STEM-oriented educational resources. As shown in Figure 1, SLR was conducted by following the PRISMA flow.

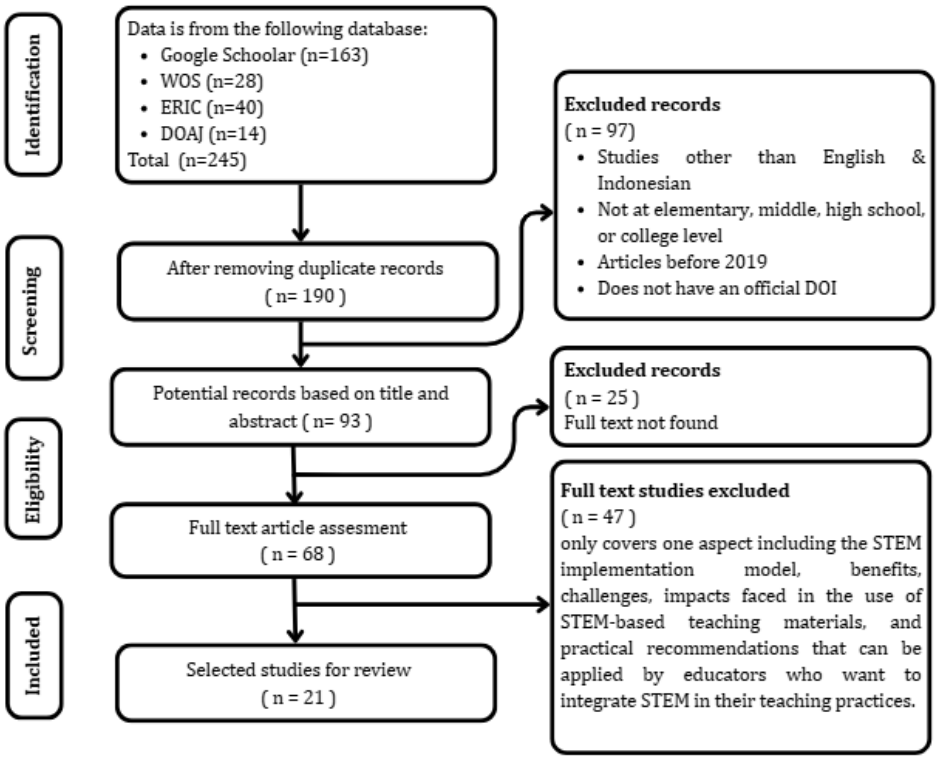

Figure 1. Four-phase Flowchart of PRISMA Guidelines

Synthesize Results

After 21 articles were collected, the next step was to analyze them systematically, starting with reading all the articles thoroughly to understand the content and essence of each article once found, then concisely recording the key points of each journal once found, then concisely recording the key points of each journal such as the purpose of the research, the methods used, the main results, and the benefits and drawbacks of utilizing STEM-focused educational tools in enhancing students' scientific literacy. The articles were also grouped by theme or research focus, such as improving science literacy, STEM-based learning effectiveness, or learning media. From these groupings, comparisons were made between journals to find patterns of similarities and differences in research results. Findings from various journals are then synthesised to develop a comprehensive understanding of the topic under study, enabling conclusions and strategic recommendations on the role of STEM-based learning media in improving students' science literacy. These articles were used as citation sources in writing scientific articles to provide a strong basis and to ensure they can be academically accounted for. Table 2 presents the findings from the examination of the 34 gathered articles.

RESULTS AND DISCUSSION

Results

Table 2. Study Analysis Results

No.	Author, Year of Publication	Title	Main Findings
1	Hamdu et al., (2021)	Learning device in the "STEMpedia" mobile learning application	The researcher created an Android mobile learning app named "STEMPedia" to serve as a resource for educators to explore STEM-based

No.	Author, Year of Publication	Title	Main Findings
			learning frameworks and obtain teaching resources. The STEMPedia app provides comprehensive teaching resources, including lesson plans, student worksheets, and STEM-based learning modules. This app has some limitations: it can only run on Android devices with version 7.0 or higher, and it may crash or close unexpectedly on older Android versions.
2	Khairani et al., (2023)	Interactive Multimedia Development Based on STEM in Improving Science Learning Outcomes	The use of STEM-based interactive multimedia improves academic outcomes in science for 5th-grade pupils at SD Negeri 104197 Klambir Village. The efficacy of engaging multimedia focused on STEM is categorised as "medium" with a gain score of 0.54. The use of STEM-based interactive multimedia increases the percentage of students who meet the minimum completeness criteria from 63.33% to 93.33%.
3	Sulistyawati et al., (2021)	Manipulative learning media based on STEM (science, technology, engineering, and mathematics) to improve student learning outcomes	Magic Hours is a hands-on learning tool developed to make learning more engaging. The results of this study proved to be valid and feasible based on the experts' evaluation. The "Magic Hours" learning media also proved practical for classroom use, as evaluated by the teachers. The "Magic Hours" educational media is successful in enhancing students' performance in mathematics, as their average score is well above the minimum passing score.
4	Hazima et al., (2024)	Implementation of STEAM and Thematic Learning Models Assisted by STEMATIK Learning Media in Elementary School	The use of STEMATIK learning media that combines STEAM and thematic learning models can significantly improve student learning outcomes. The use of STEMATIK learning media can increase students' independence and motivation to learn. STEMATIK learning media integrates various learning content, including civic education, cultural arts, and the Indonesian language, alongside mathematics.
5	Lafifa & Rosana (2023)	Development and Validation of Animation-Based Science Learning Media in the STEM-PBL Model to Improve Students' Critical Thinking and Digital Literacy	The STEM-PBL model's animation-based learning media are highly valid and suitable for use in science education. It received a 92% score from the media expert and an even higher 94% from the material expert. The assessments of the media's readability and practicality also fell into the excellent range, achieving scores of 85% and 99% respectively. The media can enhance students'

No.	Author, Year of Publication	Title	Main Findings
			abilities in critical thinking and digital literacy.
6	Artobatama et al., (2023)	STEM Learning Design with Literacy-Based Pop-Up Book Media in Elementary Schools	STEM education utilising literacy-focused Pop-Up Book resources has been developed and applied in elementary schools, and students show great enthusiasm for this learning method. Utilising literacy-centred Pop-Up Book media in STEM education can enhance students' analytical thinking, troubleshooting, decision-making, and investigative abilities. Implementing STEM education through literacy-focused Pop-Up Books encounters various obstacles, such as teachers' lack of understanding of STEM pedagogy and the need for training to address it.
7	Azizahwati et al., (2023)	Meta-analysis of the effect of STEM application on higher-order thinking skills in science learning	STEM learning is more effective at the junior high school level compared to the high school level. The PjBL (Project-Based Learning) model is the most effective STEM learning model. STEM learning using LKPD (Learner Worksheet) and modules as learning media has the highest effect size, indicating a very high impact.
8	Sakdiah et al., (2023)	Development of Augmented Reality (AR) Learning Media Integrated with STEM Learning	The created STEM-integrated AR media is regarded as highly feasible by material experts and seen as practical by media experts. The limited trial showed that the media was in the outstanding category for student practicality and the convenient category for teacher practicality. Further large-scale implementation is needed to determine the effectiveness of STEM-integrated AR media, which requires a stable internet connection.
9	Nurfadilla et al., (2022)	Science Teachers' Attitudes, Knowledge, and Practices in Applying a Gender-based STEM Approach	Both male and female science teachers had high levels of attitudes, knowledge and practices related to STEM approaches, with only slight differences between the two genders. There were no significant differences in male and female science teachers' attitudes, knowledge and practices towards STEM approaches. Male and female science teachers share similar perceptions and abilities regarding STEM approaches.
10	Agustin et al., (2022)	Meta-Analysis of the Influence of the STEM-Based Project-Based Learning (PBL)	The PjBL model, centred around STEM, showed the most significant positive effect on student learning outcomes in junior high schools, followed by high schools and

No.	Author, Year of Publication	Title	Main Findings
		Model on Science Learning	elementary schools, while demonstrating the least impact in higher education. The STEM-based PjBL model had the highest positive impact on student learning outcomes in mathematics, followed by other science subjects such as physics and biology. In contrast, the impact was moderate for chemistry. Overall, the STEM-based PjBL model has a high positive effect on student learning outcomes across different education levels and subject areas.
11	Widya et al., (2024)	Needs analysis of interactive STEM-based multimedia to enhance literacy and 21st-century skills	Students need learning media that are engaging, relevant to their daily lives, and able to foster 21st-century literacy and skills. Teachers highlight the need for practical, easily accessible educational tools that enhance student involvement in the learning experience. The development of interactive multimedia based on STEM education is needed to build students' 21st-century literacy and skills.
12	Yusuf et al., (2021)	Implementation of Online STEM-PjBL through Various Learning Platforms in Vocational High Schools during the Covid-19 Pandemic	During the COVID-19 pandemic, some teachers adopted STEM project-based learning (STEM-PjBL) in their online classrooms. Teachers utilise various online platforms, such as WhatsApp, Moodle, and Edmodo, to facilitate STEM-PJBL online learning, including for discussions and the delivery of materials. The main obstacle teachers face in implementing STEM-PjBL online learning is limited and difficult internet access.
13	Wijayanti et al., (2023)	Pengembangan Penggunaan Aplikasi Geomath Room berbasis Cience, Technology, Engineering, and Mathematic (STEM) pada Siswa	The Geomath Room app was created as a STEM-oriented digital learning resource for eighth-graders on spatial construction materials. The Geomath Room app was found to be valid, practical, and effective through expert evaluation and student testing. Learning outcomes and student satisfaction with the Geomath Room app improved after several rounds of field testing.
14	Duo & Asniza (2024)	The Effectiveness of STEM Project-based Learning on Scientific Identity: Quasi-Experimental Evidence from Chinese College Students	STEM project-based learning notably enhanced students' science identity in comparison to traditional teaching approaches. The experimental group showed higher scores across all four dimensions of science identity (interest, performance, competence, and recognition) than the control group. STEM project-based learning can be a practical approach to strengthening students' science identity,

No.	Author, Year of Publication	Title	Main Findings
			an important factor in their STEM learning and career choices.
15	Lestari & Muhajir (2024)	The Development of Hydraulic Robotic Arm as a STEM-Based Physics Learning Media	The hydraulic robot arm demonstrated its effectiveness as a STEM-oriented physics learning tool, as evaluated by specialists in materials and learning media. The incorporation of hydraulic robotic arms into STEM education helps students grasp the practical application of pressure principles, particularly those related to Pascal's Law. Utilising STEM-oriented hydraulic robotic arms can enhance students' critical and creative thinking, boost self-confidence, and develop problem-solving abilities.
16	Kurniawan et al., (2023)	Effectiveness of STEM-Based Lectora Inspire Media to Improve Students' HOTS in Physics Learning	The STEM-focused Lectora Inspire media is an efficient learning resource for students, as evidenced by high scores from subject-matter and media experts. Both science teachers and students rated STEM-based Lectora Inspire media as very practical and efficient for learning. The use of STEM-based Lectora Inspire media significantly improved students' higher-order thinking skills (HOTS).
17	Melita et al., (2023)	Development of STEM-Based Physics Learning Media Materials on Temperature and Heat to Improve Students' Mastery of Concepts	STEM-oriented physics education resources, represented by a digital calorimeter, are deemed highly valid, achieving an average Aiken-V score of 0.94 and a reliability rate of 93% across all associated tools. STEM-based physics learning media is considered practical, with an implementation score of 70% in each learning phase, and received positive responses from students and teachers. STEM-based physics learning media is considered effective in improving students' concept mastery, with a mean N-gain score of 0.61, placing it in the medium range.
18	Zulirfan & Yennita (2022)	Feasibility test of STEM at Home Prototype Kit as Science Project-Based Learning Media for Junior High School students	The STEM Project Kit for Home and Worksheets, developed for the topic of Simple Machines, has been validated by experts and found suitable for use as learning media. One-on-one and small-group evaluations with students indicated that the Home STEM Project Kits and Worksheets are easy to use, flexible, and effective at enhancing students' critical and creative thinking skills. The Home STEM Project Kits and Worksheets were found to be flexible in terms of location and timing,

No.	Author, Year of Publication	Title	Main Findings
			with most students able to work on the projects independently at home.
19	Irfana et al., (2022)	The Effectiveness of STEM-Based Android-Based Learning Media on Students' Critical Thinking Skills	Learning media based on Android and employing a STEM approach successfully enhances students' critical thinking abilities, as evidenced by a significant N-gain of 0.77. The evaluation and conclusion sections demonstrate the most significant improvement in students' analytical thinking skills. The findings indicated that Android-based learning media with a STEM approach effectively enhance students' critical thinking abilities.
20	Halim et al., (2023)	Effect of environmental factors on students' interest in STEM careers: The mediating role of self-efficacy	Students' confidence in their own abilities (self-efficacy) plays a central role in linking external influences, such as family support, media exposure, and learning experiences beyond school, to their interest in pursuing STEM careers. While in-school learning experiences did not show a significant effect, media and informal learning proved effective in increasing students' self-efficacy and interest. These findings confirm the importance of strengthening students' STEM learning experiences and STEM self-efficacy through meaningful STEM learning experiences outside the formal classroom to promote interest in STEM careers.
21	Wang et al., (2021)	Promoting STEM Learning through an Interdisciplinary Video Project	Explores the effectiveness of interdisciplinary video projects in enhancing STEM learning in higher education. Through collaboration among students from different disciplines, the initiative promotes the development of critical thinking, problem-solving, and communication skills. The results show that this approach not only deepens students' understanding of STEM concepts but also increases their motivation and engagement in the learning process. Thus, integrating interdisciplinary video projects can be an effective strategy for enriching STEM learning experiences in academic settings.

Discussion

Effect of STEM-based Learning Media in Improving Students' Science Literacy

Using STEM-based learning media has a substantial impact on improving students' science literacy, particularly their ability to make sense of and use scientific concepts in everyday situations. STEM-based media integrates a cross-disciplinary approach to science, technology, engineering, and

mathematics, simultaneously honing critical thinking, problem-solving, and evidence-based decision-making skills. Research shows that the application of project-based STEM learning media can effectively improve science literacy by engaging students in designing, testing, and evaluating scientific solutions to real-world problems (Duo & Ishak, 2024).

STEM media that are designed interactively and contextually also encourage students to understand the relationship between scientific concepts in everyday life. For example, through the development of interactive multimedia equipped with Android-based visualisation and Augmented Reality, students can understand science concepts more concretely, thereby improving their science literacy (Irfana et al., 2022; Sakdiah et al., 2023). Other studies confirm that the use of STEM-based media, such as digital physics modules and manipulative teaching aids, can significantly improve the ability to understand and apply science concepts (Melita et al., 2023; Sulistyawati et al., 2021). Furthermore, science literacy is not limited to conceptual aspects; it also involves the ability to make scientific arguments and evaluate information. STEM-based media, such as educational videos resulting from collaborations between students in science and digital media, have been proven effective in improving understanding and communication of complex scientific concepts (Wang et al., 2021). In addition, research shows that the use of contextualised STEM multimedia, such as interactive media with healthy food or energy themes, can help students relate science to their surrounding environment, thereby increasing engagement and understanding (Khairani et al., 2023).

Additional support comes from a meta-analysis that found STEM-based learning approaches have a significant influence on improving scientific literacy, especially when combined with project-based learning models and specially designed student worksheets (LKPD) (Azizahwati et al., 2023; Agustin et al., 2022). The integration of STEM media in the form of modules, Android applications, and animated videos has also been shown to improve aspects of digital literacy, an important part of digital-era science literacy (Kurniawan et al., 2023; Lafifa & Rosana, 2023).

Thus, based on these studies' results, STEM-based learning media play an important role in improving students' science literacy through interactive, contextual, and applicable learning. This media not only improves conceptual understanding but also develops scientific thinking and digital literacy skills, both of which are highly relevant to addressing the challenges of the 21st century.

Characteristics of Effective STEM-based Learning Media in the Context of Science Learning

The characteristics of effective STEM-based learning media in the context of science learning have several key elements that are interconnected to support students' overall science literacy. Effective media must integrate elements of Science, Technology, Engineering, and Mathematics into a learning approach that is contextual, interactive, and supports 21st-century skills. One of the main characteristics is the active involvement of students in the learning process through challenging, problem-based projects or activities relevant to real life. STEM learning media that use a project-based approach have been proven to significantly improve students' scientific identity and science learning outcomes (Duo & Ishak, 2024).

The effectiveness of STEM media is also strongly influenced by aspects of interactivity and technological accessibility. The use of interactive media based on Android and Augmented Reality (AR) has been proven to improve students' critical thinking skills and mastery of science concepts, with high validity and effectiveness across multiple trials (Irfana et al., 2022; Sakdiah et al., 2023). Interactive multimedia has also shown high effectiveness in developing 21st-century literacy and skills, with an emphasis on contextually relevant content that is easily accessible to students and teachers (Widya et al., 2024). Furthermore, STEM media designed with systematic development models such as 4D and ADDIE demonstrate high validity and practicality and have a positive impact on student learning outcomes. For example, the development of digital media such as the digital calorimeter and Lectora Inspire led to a significant increase in students' mastery of concepts and higher-order thinking skills (Melita et al., 2023; Kurniawan et al., 2023).

The integration of manipulative elements or home-based kits is also considered important in strengthening the practical application of science concepts, with high validity in terms of content and design, and received positive responses from students (Zulirfan & Yennita, 2022; Sulistyawati et al., 2021). Furthermore, the effectiveness of STEM media in improving higher-order thinking skills (HOTS) has been confirmed through a meta-analysis that showed large effect sizes for indicators

such as problem-solving and critical thinking, with LKPD and modules being the most effective (Azizahwati et al., 2023). Other research supports the idea that STEM media that include visual and audio elements, such as educational videos and animations, also have a significant impact on improving students' communication skills, digital literacy, and interest in science learning (Wang et al., 2021; Lafifa & Rosana, 2023).

Thus, effective STEM learning media in science learning are characterised by the integration of real-life context, a project-based approach, the utilisation of interactive technology, the strengthening of higher-order thinking skills, and high instructional design validity. Such media play a crucial role in holistically and sustainably improving students' science literacy.

Factors Influencing the Successful Implementation of STEM-based Learning Media

A range of internal and external factors influences the successful implementation of STEM-based learning media in schools. One key factor is teachers' readiness and competence in designing and implementing STEM media effectively. Teachers with knowledge, positive attitudes, and skills in an interdisciplinary approach will be better able to optimise learning media to improve students' understanding of science (Nurfadilla et al., 2022). In addition, teacher training and technical support in using STEM media are also important for optimal implementation (Hamdu et al., 2021). The next factor is the design and characteristics of the STEM media itself. Media designed using the ADDIE or Design-Based Research approach, and with high validity and practicality scores from experts and users, tend to be more successfully implemented in learning. For example, media-based manipulatives, interactive modules, and digital applications such as STEMATIK and Geomath Room have proven effective and practical in primary and secondary school settings (Hazima et al., 2024; Wijayanti et al., 2023).

The learning environment also determines success. Research shows that family factors, learning experiences outside school, and the availability of supporting facilities, such as internet access and digital devices, greatly influence the effectiveness of STEM learning, especially in online or home-based learning conditions (Halim et al., 2023; Zulirfan & Yennita, 2022). Success is also largely determined by the relevance of local context and by curriculum integration. Media that link STEM learning to everyday themes, such as renewable energy, hydropower, or environmental projects, have been shown to increase students' engagement in learning while helping them better understand concepts and think more critically (Sulistyawati et al., 2021; Lestari & Muhajir, 2024). Finally, institutional support and school policies are important factors. Schools that support learning innovation, provide time for teaching experiments, and have a collaborative culture among teachers will be more successful in adopting STEM-based learning media. In this context, systematic implementation, such as the use of digital platforms during the pandemic or the adoption of a structured STEM thematic curriculum, also contributes to the program's success (Yusuf et al., 2021; Artobatama et al., 2023).

Thus, the successful use of STEM-based learning tools in schools results from a complex interaction among teacher competence, media design, support for the learning environment, relevance to local context, and educational institution policy.

CONCLUSION

STEM-based learning media have a significant role in improving students' science literacy at various levels of education. It has been proven to strengthen understanding of scientific concepts, develop critical thinking skills, and improve students' digital literacy through contextual, interactive, and project-based learning approaches. Characteristics of effective STEM media include the use of technology such as interactive multimedia, augmented reality, and digital applications that are relevant to real life, as well as valid and practical instructional design. The successful implementation of this media is strongly influenced by teacher competence, support for the learning environment, relevance to the local context, and support from educational institution policy. Therefore, integrating STEM-based learning media into educational practices is not only an innovative solution but also a strategic necessity to equip students with comprehensive, relevant science literacy to address the challenges of the 21st century. Future research is recommended to explore the long-term impact of

STEM-based learning media on students' science literacy across diverse educational levels and cultural contexts, and to develop adaptive digital tools that support personalised learning and teacher facilitation.

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REFERENCES

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs STEAM education and student creativity: A systematic literature review. *Education Sciences*, *11*(7), 1-13. https://doi.org/10.3390/educsci11070331

Agustin, Y., Lufri, Ali Amran, & Ellizar. (2022). Meta-analysis of the influence of the STEM-based project based learning (PjBL) model on science learning. *International Journal of Humanities Education and Social Sciences (IJHESS)*, *2*(3), 1040-1053. https://doi.org/10.55227/ijhess.v2i3.331

Aini, N., Jalmo, T., & Abdurrahman. (2020). The prospective of STEM education: Students' perceptions about the role of interest growth in science literacy. *Journal of Physics: Conference Series, Volume 1572, The 9th International Conference on Theoretical and Applied Physics (ICTAP) 26-28 September 2019, Bandar Lampung, Indonesia*, *1572*, 1-6. https://doi.org/10.1088/1742-6596/1572/1/012083

Ariefianti, M., Sholahuddin, A., & Wati, M. (2023). The validity of the student worksheet of thermal energy material based on science, technology, engineering, mathematics (STEM) and local wisdom to enhance scientific literacy. *Jurnal Ilmiah Pendidikan Fisika*, *7*(3), 487-499. https://doi.org/10.20527/jipf.v7i3.9379

Artobatama, I., Hastuti, W. S., Zubaidah, E., & Wibowo, S. E. (2023). STEM learning design with literation-based pop-up book media in elementary schools. *Jurnal Prima Edukasia*, *11*(2), 152–160. https://doi.org/10.21831/jpe.v11i2.56628

Ashiq, M., Jabeen, F., & Mahmood, K. (2022). Transformation of libraries during COVID-19 pandemic: A systematic review. *Journal of Academic Librarianship*, *48*(4), 1-10. https://doi.org/10.1016/j.acalib.2022.102534

Aswirna, P., Kiswanda, V., Nurhasnah, N., & Fahmi, R. (2022). Implementation of STEM e-module with SDGs principle to improve science literacy and environment-friendly attitudes in terms of gender. *JTK (Jurnal Tadris Kimiya)*, *7*(1), 64–77. https://doi.org/10.15575/jtk.v7i1.16599

Azizahwati, A., Januarti, J., Sari, S. W., Sari, R. A., Ranti, L., & Septyowaty, R. (2023). Meta analysis of the effect of STEM application on higher order thinking skill in science learning. *Momentum: Physics Education Journal*, *7*(1), 154–163. https://doi.org/10.21067/mpej.v7i1.7959

Duo, H., & Ishak, N. A. (2024). The effectiveness of STEM project-based learning on scientific identity: Quasi-experimental evidence from Chinese college students. *International Journal of Academic Research in Progressive Education and Development*, *13*(3), 1151-1161. https://doi.org/10.6007/ijarped/v13-i3/21868

Falloon, G., Hatzigianni, M., Bower, M., Forbes, A., & Stevenson, M. (2020). Understanding K-12 STEM education: A framework for developing STEM literacy. *Journal of Science Education and Technology*, *29*(3), 369–385. https://doi.org/10.1007/s10956-020-09823-x

Halim, L., Mohd Shahali, E. H., & H Iksan, Z. (2023). Effect of environmental factors on students' interest in STEM careers: The mediating role of self-efficacy. *Research in Science and Technological Education*, *41*(4), 1394–1411. https://doi.org/10.1080/02635143.2021.2008341

Hamdu, G., Mulyadiprana, A., Mukti, H., Yulianto, A., & Karlimah, K. (2021). Learning device in the "STEMpedia" mobile learning application. *Journal of Physics: Conference Series, Volume 1987, Seminar on Advances in Mathematics, Science, and Engineering for Elementary Schools (SAMSES) 2020, 8 October 2020, Jawa Barat, Indonesia*, *1987*, 1-8. https://doi.org/10.1088/1742-6596/1987/1/012014

Harpian, Suwarma, I. R., & Setiawan, A. (2023). The application of STEM learning to improve students' STEM literacy in the knowledge aspect. *Journal of Innovation in Educational and Cultural Research*, *4*(3), 450–457. https://doi.org/10.46843/jiecr.v4i3.676

Hazima, A. A., Prasetyo, E., Annisa, A. H., & Maryanti, R. (2024). Implementation of STEAM and thematic learning models assisted by STEMATIK learning media in elementary school. *Mathematics Education Journal*, *8*(2), 159-171. https://doi.org/10.22219/mej.v8i2.34029

Irfana, S., Hardyanto, W., & Wahyuni, S. (2022). The effectiveness of STEM-based Android-based learning media on students' critical thinking skills. *Physics Communication*, *6*(1), 12–17. https://doi.org/10.15294/physcomm.v6i1.35726

Karimah, F., & Wulandari, F. (2023). The influence of an integrated STEM project-based learning toward science literacy abilities students in elementary school. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 10446–10456. https://doi.org/10.29303/jppipa.v9i11.4171

Khairani, L. A., Djulia, E., & Bunawan, W. (2023). Interactive multimedia development based on STEM in improving science learning outcomes. *Randwick International of Education and Linguistics Science Journal*, *4*(2), 428–435. https://doi.org/10.47175/rielsj.v4i2.719

Kurniawan, A., Tantri, I. D., & Fian, K. (2023). Effectiveness of STEM-based Lectora Inspire media to improve students' HOTS in physics learning. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *9*(1), 55–66. https://doi.org/10.21009/1.09106

Lafifa, F., & Rosana, D. (2023). Development and validation of animation-based science learning media in the STEM-PBL model to improve students critical thinking and digital literacy. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 7445–7453. https://doi.org/10.29303/jppipa.v9i9.4448

Lestari, I. F., & Muhajir, S. N. (2024). The development of hydraulic robotic arm as a STEM-based physics learning media. *JIPF (Jurnal Ilmu Pendidikan Fisika)*, *9*(1), 88-94. https://doi.org/10.26737/jipf.v9i1.4743

Melita, A. S., Doyan, A., & Makhrus, M. (2023). Development of STEM-based physics learning media materials on temperature and heat to improve students' mastery of concepts. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 2144–2150. https://doi.org/10.29303/jppipa.v9i4.3726

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Journal of Clinical Epidemiology*, *62*(10), 1006–1012. https://doi.org/10.1016/j.jclinepi.2009.06.005

Nurfadilla, E., Halim, A., Supriatno, S., Yusrizal, Y., & Mursal, M. (2022). Science teachers' attitudes, knowledge, and practices in applying a gender-based STEM approach. *Jurnal Penelitian Pendidikan IPA*, *8*(3), 1489–1494. https://doi.org/10.29303/jppipa.v8i3.1704

Ramulumo, M. (2024). Exploring the impact of early STEM education on science and visual literacy. *Journal of Education in Science, Environment and Health*, *10*(3), 216–229. https://doi.org/10.55549/jeseh.725

Sakdiah, H., Andriani, R., Ginting, F. W., & Fatmi, N. (2023). Development of augmented reality (AR) learning media integrated with STEM learning. *Jurnal Penelitian Pendidikan IPA*, *9*(SpecialIssue), 487–493. https://doi.org/10.29303/jppipa.v9ispecialissue.6043

Santos, B. S. F., Murti, R. C., Limiansih, K., & Tahu, G. P. (2023). Scientific literacy in hybrid learning with the STEM approach for the students of primary school teacher education. *QALAMUNA: Jurnal Pendidikan, Sosial, dan Agama*, *15*(2), 657–666. https://doi.org/10.37680/qalamuna.v15i2.2839

Setiawan, A. R. (2019). Developing STEM education's lesson plan for guide students to achieve scientific literacy. http://dx.doi.org/10.31219/osf.io/stb8x

Sole, F. B. (2021). Implementation of STEM-based learning for strengthening science literacy of students. *Jurnal Penelitian Pendidikan IPA*, *7*(SpecialIssue), 382–388. https://doi.org/10.29303/jppipa.v7ispecialissue.1266

Sulistyawati, E., Puspitasari, D., Saidah, Z. N., & Rofiqoh, I. (2021). Manipulative learning media based on stem (science, technology, engineering, and mathematics) to improve student learning outcomes. *MaPan*, *9*(1), 1-13. https://doi.org/10.24252/mapan.2021v9n1a1

Wahono, B., Husna, A., Hariyadi, S., Anwar, Y., & Meilinda, M. (2023). Development of integrated STEM education learning units to access students' systems thinking abilities. *Jurnal Inovasi Teknologi Pendidikan*, *10*(1), 1–9. https://doi.org/10.21831/jitp.v10i1.52886

Wang, C., Shao, Q., Li, X., Mao, W., & Roberts, L. A. (2021). Promoting STEM learning through an interdisciplinary video project. *2021 19th International Conference on Information Technology Based Higher Education and Training, ITHET 2021*, Sydney, Australia, 2021, pp. 1-9. https://doi.org/10.1109/ITHET50392.2021.9759770

Widya, W., Mujtahid, Z., Muliaman, A., & Hidayat, A. T. (2024). Needs analysis of interactive STEM-based multimedia to enhance literacy and 21st-century skills. *Indonesian Journal of Science and Mathematics Education*, *7*(3), 590-599. https://doi.org/10.24042/ijsme.v7i3.23709

Wijayanti, N. M. W., Sukendra, I. K., & Purwati, N. K. R. (2023). Pengembangan penggunaan aplikasi Geomath Room berbasis STEM pada siswa Kelas VIII di SMPN 11 Denpasar. *Widyadari*, *24*(2), 333-347. https://doi.org/10.59672/widyadari.v24i2.4443

Yepes-Nuñez, J. J., Urrútia, G., Romero-García, M., & Alonso-Fernández, S. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Revista Espanola de Cardiologia*, *74*(9), 790–799. https://doi.org/10.1016/j.recesp.2021.06.016

Yusuf, A. R., Marji, Sutadji, E., & Sugandi, M. (2021). Implementation of online STEM-PjBL through various learning platforms in vocational high schools during COVID-19 pandemic. *Elementary Education Online*, *20*(2), 1-8. https://ilkogretim-online.org/index.php/pub/article/view/2741

Zulirfan, Z., & Yennita, Y. (2022). Feasibility test of STEM at home prototype kit as science project-based learning media for Junior High School students. *Jurnal Penelitian Pendidikan IPA*, *8*(1), 57–66. https://doi.org/10.29303/jppipa.v8i1.1122