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STEM-based Teaching Materials to Support Scientific Literacy and Sustainability Awareness: A Critical Review

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Abstract

STEM education, an innovative approach fostering Science, Technology, Engineering, and Mathematics skills, stands as an alternative method to cultivate 21st-century competencies. It emphasizes innovation while teaching materials serve as resources aiding instructors in classroom teaching and learning activities. An analysis of published articles in national and international journals focused on examining trends in STEM education and teaching materials. Out of 18 collected articles meeting specific criteria, findings underscore the capacity of STEM education and associated teaching materials to enhance scientific literacy and promote sustainability awareness. Notably, when leveraging STEM-based teaching materials, significant advancements in these areas are evident. However, further empirical research is warranted to comprehensively explore the potential of STEM-based Teaching Materials in augmenting scientific literacy and fostering sustainability awareness.

Introduction

In the pursuit of elevating scientific literacy among students, our research delves into a critical examination of the prevailing challenges and innovative solutions at the intersection of STEM education and teaching materials. The landscape of science education faces a significant hurdle as studies, including those by Jufrida et al., (2019), Adnan et al., (2021), Suprapto et al., (2022), and Kaur and Kaur (2022), consistently reveal suboptimal levels of achievement in scientific literacy. Factors that affect science literacy are divided into internal factors and external factors. One of the factors is due to the lack of facilities in schools for lessons that train science literacy, lack of use of teaching materials, interactive learning media can affect science literacy skills (Jufrida et al., 2019; Suprapto et al., 2020). Therefore, it is necessary to develop a science literacy E-book or interactive multimedia supported by learning tools such as syllabus, lesson plans, worksheets, and assessment sheets (Widodo et al., 2020; Adnan et al., 2021; Suprapto et al., 2022).

In addition to interactive teaching materials, teachers are encouraged to start introducing and teaching material using various strategies with a science literacy aspect, including teaching material through experiments that can stimulate higher-level thinking and are contextual in nature, so that students' science literacy skills and new

literacy can improve properly (Asrizal et al., 2023; Muhlis et al., 2024). Velázquez & Rivas, (2020); Campbell et al., (2021); Asrizal et al., (2023) highlighted the potential of science learning in improving new literacy and sustainability awareness through a STEM approach.

The STEM approach involves the integration of science, technology, engineering, and mathematics, as outlined by Torlakson (2014). This method aims to harmoniously combine these four disciplines by addressing real-world problems, aligning learning with practical problem-solving applicable in daily and professional life. By integrating STEM into education, it facilitates the development of 21st-century skills through contextualized learning that directly relates to real-life challenges. Furthermore, the integration of STEM offers teachers and students more pertinent and engaging learning experiences, ultimately boosting student motivation and academic achievement, as noted by the National Research Council (NRC, 2014). Bybee (2013) suggests that the development of educational science should begin to consider STEM learning as a crucial way to address the challenges and demands of this century. The STEM approach in education is recognized as a strategy widely used by teachers to improve students' science literacy, and to integrate sustainable education that focuses on environmental awareness of understanding related to SDGs (Velázquez & Rivas, 2020; Campbell et al., 2022).

The critical analysis review intends to delve into the prevalent themes within STEM education and teaching materials research pertaining to science learning between October 2019 and January 2024. It seeks to scrutinize the implementation of STEM education and teaching materials in the context of science learning, with a specific focus on scholarly articles published in Scopus journals over the last five years. This review aims to identify factors that predict scientific literacy and sustainability awareness while proposing potential directions for future research in this domain.

The article structure commences with an introductory section, providing a comprehensive overview of STEM education and teaching materials. Subsequently, it delineates the methodology employed for conducting the critical analysis review. Following this, the review's core section unfolds, detailing the findings and engaging in discussions around the most explored topics in STEM education and teaching materials research concerning science learning. This section critically examines the implementation aspects of STEM education and teaching materials in the context of science learning.

Further, the review dedicates a segment to scrutinize the predictors of students' scientific literacy and sustainability awareness based on an analysis of recent scientific research articles from Scopus journals. It explores and discusses these predictors to understand their implications for enhancing science learning outcomes. Finally, the review concludes by synthesizing the key takeaways, summarizing the findings, and offering suggestions for future research trajectories in this dynamic area of STEM education and teaching materials.

As researchers embark on this thorough investigation, their primary objective is not only to identify the current shortcomings and challenges but also to offer practical insights that can pave the way for a transformative shift in science education. By closely examining the complex interplay between STEM (Science, Technology, Engineering, and Mathematics) and educational resources, the goal is to contribute to the creation of a robust and

revolutionary educational framework. This framework aims not only to address the current deficiencies in scientific literacy but also to foster a profound comprehension of sustainability, thereby nurturing thoughtful and skilled leaders for the future.

Method

Research Design

A critical analysis review represents a thorough and meticulous evaluation of a subject matter undertaken by scholars within a specific field. These researchers utilized methodologies commonly employed in this type of research, aiming to furnish readers with a comprehensive understanding of the existing knowledge on a particular topic while proposing potential avenues for future research. Additionally, the researchers endeavored to critically scrutinize deficiencies in current theories, methodologies, and conceptual or empirical findings within the subject area. This methodical evaluation involves scrutinizing the subject's components, strengths, and weaknesses, with the goal of providing an insightful and nuanced interpretation. The researchers aim to contribute to the existing body of knowledge by offering a comprehensive and well-founded perspective on the subject (Wallace and Wray, 2016; Cottrell, 2017). The choice of this method is justified as it allows for a thorough and in-depth exploration of STEM-based teaching materials, ensuring a meticulous examination of their impact on scientific literacy and sustainability awareness.

The researchers carried out the investigation in the form of a “state-of-the-art review" (Grant & Booth, 2009) and utilized methodologies commonly associated with this type of research. The main objective was to provide readers with an understanding of the existing knowledge on a particular topic and to suggest potential directions for future research. As a result, the study did not aim to conduct an exhaustive search, offer a retrospective analysis of past research, or establish a definitive set of best practices within the field. Rather, the emphasis was on critically assessing deficiencies in current theoretical frameworks, research methodologies, and conceptual or empirical findings. Employing a critical analysis review with a content analysis approach, the study examined scientific articles related to STEM education, teaching materials, scientific literacy, and sustainability awareness in science subjects, from October 2019 to January 2024, with a focus on overseas context.

Population and Sampling

The research sample comprises 18 articles sourced from the period between October 2019 and January 2024, extracted from Google Scholar, Garuda, and SCOPUS databases within the realm of STEM education and teaching materials. These articles were identified using specific keywords such as "STEM Education," "Teaching Materials," and "STEM-based Teaching Materials."

Data Collections Process

The review process involved several key stages:

1. Data Selection: This step included formulating research questions and identifying articles relevant to the study.

Criteria for inclusion were established, as outlined in Table 1. Articles were screened across multiple databases (Google Scholar, Garuda, and SCOPUS) using Publish or Perish software. Researchers narrowed down the selection based on the predetermined criteria, resulting in the examination and analysis of 18 manuscripts. The review process involved assessing abstracts initially and then comprehensively reading the entire content of the selected articles.

2. Coding Instrument Adaptation: The researchers utilized a Paper Classification Form (PCF) developed by Kizilaslan et al., (2012) as the basis for their coding instrument. The PCF, known for its validity and reliability, encompassed various indicators such as title, author details, journal information, publication year, journal type, language, indexing, primary discipline, research methodologies, data collection methods, sample details, and data analysis techniques. Additionally, researchers created a data matrix containing information on research purposes, integrated learning models, thematic elements, and key findings. The collected data underwent analysis using percentage calculations.

3. Identifying Article Patterns: The researchers aimed to identify patterns within the selected articles, particularly focusing on findings, integration of STEM education, teaching materials, and the skills attained. These patterns were synthesized to address the research questions posed in the study.

4. Synthesizing Patterns to Address Research Questions: Figure 1 illustrates the process of synthesizing identified patterns to effectively address the research questions established in the study. This step involved integrating and analyzing the patterns identified across the selected articles to provide comprehensive answers to the research inquiries.

Data Analysis

During this phase, the researchers conducted calculations to determine the percentage distribution of each finding obtained from the selected articles. This information was organized and presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

No.	Category	Inclusion Criteria	Exclusion Criteria
1.	Type of Publication	Articles published in journals	Articles published in conference proceedings, books, websites, blogs, and other similar sources.
2.	Journal Specifications	International journal minimum indexed Scopus.	National journal not accredited or accredited by Sinta 2 until 5.
3.	Publication Year	2019 - 2024	Less than 2019
4.	Research Setting	Qualitative (Descriptive), Quantitative (Experimental), Mixed Method, Research and Development.	Systematic Literature, Literature Review, Comparative Study, Phenomenology.
5.	Research Nationality	A collaboration of Indonesians and Foreigners	Only Indonesians
6.	Independent	STEM or Teaching Materials	Not STEM or Teaching Materials

No.	Category	Inclusion Criteria	Exclusion Criteria
	Variable		
7.	Field	Science (Chemistry, Physics, and Biology)	Outside of science
8.	Research Subject	Students informal education includes secondary school, senior high school	Students and Teachers in non-traditional educational settings, such as special needs schools or nonformal schools, were part of the study. Additionally, participants engaged in informal education covered a wide range from early childhood schools, elementary & high schools, to universities.

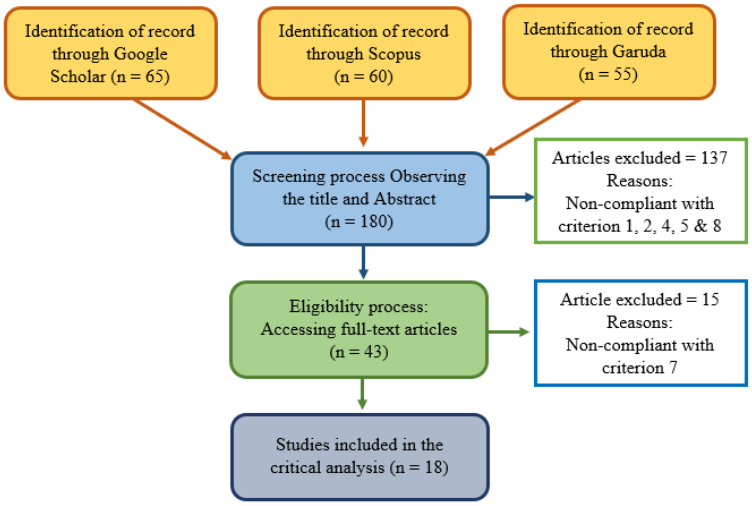

Figure 1. Flowchart of the article selection procedure

Findings

This critical review analyzes articles published between October 2019 and January 2024 that were conducted internationally. The distribution of these articles was based on specific inclusion criteria, which included nationally accredited journals categorized as Sinta 1, as well as international journals indexed by Scopus under various quartiles (Q1, Q2, Q3, and Q4), as detailed in Table 2.

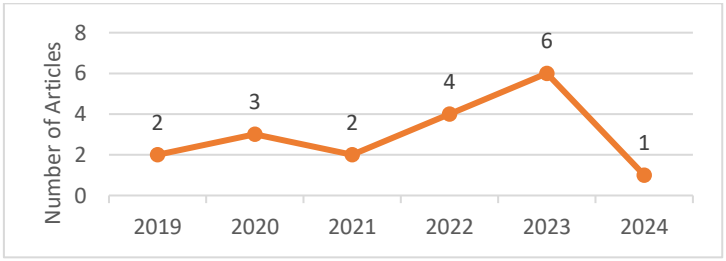

Figure 2. Distribution of Article by Year Published

Findings from the analysis revealed the diverse utilization of research methods in STEM education, teaching materials, scientific literacy, and sustainability awareness studies across different countries. Specifically, research in these domains has been conducted in various countries worldwide. The distribution of STEM, teaching materials, scientific literacy, and sustainability awareness research in science learning, depicted in Figure 3, highlights Indonesia as the most prevalent location for the implementation of STEM education, teaching materials, and their integration into science learning. Moreover, several other countries have also begun adopting and implementing STEM practices, as depicted in Figure 3.

Table 2. Distribution of Articles with Journal Identification

Journal	**Country of Origin**	**Quartile***	**SJR 2022****	**H-index**
TEM Journal	Serbia	Q3	0.23	17
Pegem Journal of Education and Instruction	Turkey	Q4	0.18	7
Interactive Learning Environments	United Kingdom	Q1	1.17	57
International Journal of Emerging Technologies in Learning	Austria	Q2	0.54	39
International Journal of Advanced Computer Science and Applications	United Kingdom	Q3	0.26	35
Sustainability	Switzerland	Q1	0.66	136
International Journal of Evaluation and Research in Education (IJERE)	Indonesia	Q3	0.31	14
Eurasia Journal of Mathematics, Science and Technology Education	Turkey	Q2	0.51	50
International Journal of Child-Computer Interaction	Netherlands	Q1	33	1.07
Heliyon	Netherlands	Q1	0.61	69
Journal on Efficiency and Responsibility in Education and Science	Czech Republic	Q3	0.29	9
Jurnal Pendidikan IPA Indonesia	Indonesia	Q3	0.36	23
International Journal of Environmental Research and Public Health	Switzerland	Q2	0.83	167
International Journal of Instruction	Switzerland	Q2	0.61	32

** Quartile based on 2023 SCImago*

*** SJR column based on 2022 SCImago*

Table 3. The Trend of STEM Education, Teaching Materials from Research Methods

Approach	**Research Methods**	**Frequency**	**Percentage (%)**
Qualitative	Descriptive-Qualitative	1	5.5%
Quantitative	Descriptive Causal Comparative	1	5.5
	Experiment	6	33.3
	Correlational	1	5.5

Approach	Research Methods	Frequency	Percentage (%)
	Survey	2	11.1
Other	Mixed Method	3	16.6
	Research and Development	4	22.2

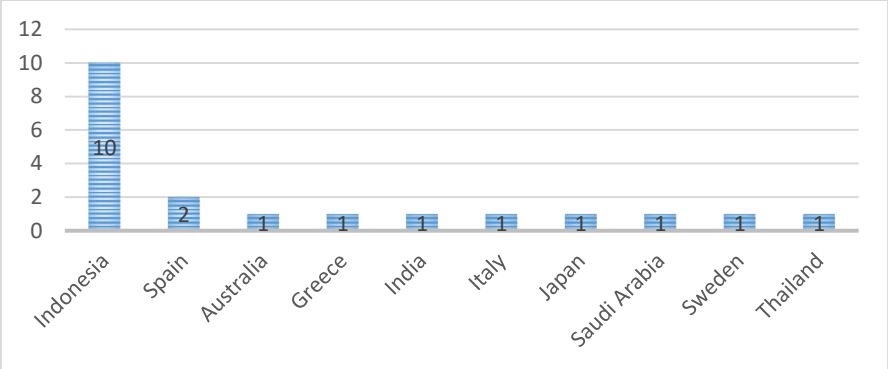

Figure 4. Distribution of STEM Education, and Teaching Materials Implementation Research Locations

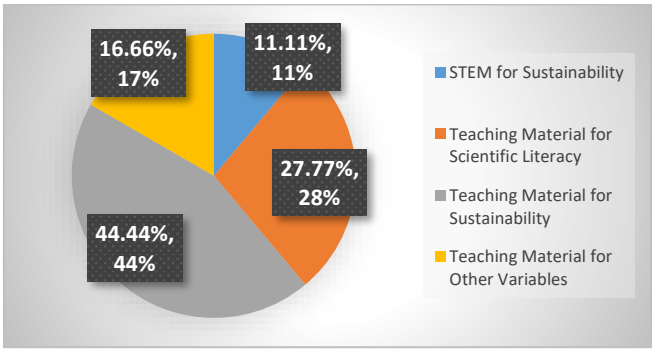

Figure 5. Distribution of STEM Education and Teaching Materials in Science Learning

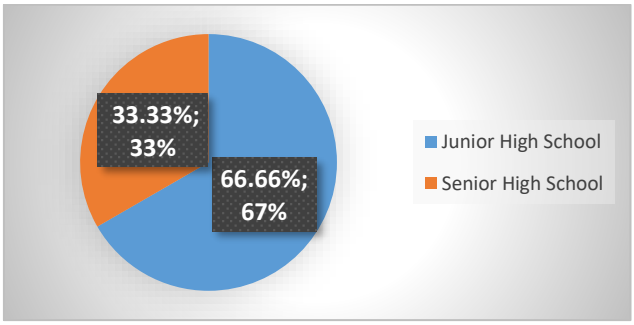

Figure 6. Distribution of Integration of STEM Education and Teaching Materials Education at Each Level

To analyze the countries contributing the most research on STEM and teaching materials, the researchers examined the authors' country of affiliation in academic articles. The distribution of these articles spans across 8 countries. As illustrated in Table 4, Indonesia stands out by contributing 55.5% of the articles related to STEM and teaching materials, making it the primary contributor. Following Indonesia, Spain accounted for 11.1% of the articles in this domain.

Table 4. Countries of Affiliation Journals from January 2019 to January 2024

Country affiliations	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**Total**	**%**
Indonesia	2	2	1	2	2	1	10	55.5
Japan					1		1	5.5
Australia				1			1	5.5
Spain		1			1		2	11.1
Saudi Arabia					1		1	5.5
Greece					1		1	5.5
Thailand			1				1	5.5
India				1			1	5.5
Total	**2**	**3**	**2**	**4**	**6**	**1**	**18**	**100**

The countries included in the analysis, namely Indonesia, Japan, Australia, Spain, Saudi Arabia, Greece, Thailand, and India, were grouped together as they each contributed only one research paper between 2019 and 2024. Table 5 illustrates the origin countries of the journals where these research articles were published. Switzerland emerged with the highest number of publications, totaling 6 articles, followed by Indonesia with 3 articles. Collectively, these two countries accounted for half (50%) of the total articles analyzed in this study.

Table 5. Origin Countries of the Journals from October 2023 to January 2024

Source Country	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**Total**	**%**
Serbia				1			1	5.5
Turkey					1	1	2	11.1
United Kingdom				1	1		2	11.1
Austria	1	1					2	11.1
Switzerland		1	1	1	2		6	33.3
Indonesia	1	1			1		3	16.6
Netherlands			1		1		2	11.1
Czech Republic				1			1	5.5
Total	**2**	**3**	**2**	**4**	**6**	**1**	**18**	**100**

Table 2 provides details regarding the 18 journals contributing to this literature review, categorized based on their impact factors. Notably, the "International Journal of Child-Computer Interaction" stands out with the highest impact index, boasting an SJR (Scimago Journal Ranking) of 33. The study's findings highlight four integration/applied approaches in the implementation of STEM and teaching materials, illustrated in Figure 5.

The integrated approach of STEM education with teaching materials has seen extensive use in the implementation of science learning overseas. Additionally, other variables such as STEM for sustainability, teaching materials for scientific literacy, and teaching materials for sustainability awareness have also been applied in science learning. Implementing science learning through the integration of STEM education with teaching materials facilitates the development of competencies aligned with learning objectives. STEM education and teaching materials have been

widely implemented across various levels of education overseas, with a particular emphasis observed at the secondary school level (Figure 6).

The integration of STEM and teaching materials into learning processes can be carried out through diverse learning strategies, as detailed in Table 6. Furthermore, STEM education commonly correlates with specific thematic approaches in research, as indicated by the distribution of findings presented in Table 6 and Table 7. These tables depict the integration or absence of learning strategy with teaching materials.

Table 6. Integration Learning Strategy with Teaching Materials

Learning Strategy	Percentage (%)	References
Scientific Literacy	4 (22,22)	Suprapto *et al.,* (2022); Asrizal *et al.,* (2023); Widodo *et al.,* (2020); Subali *et al.,* (2023)
Sustainability	4 (22,22)	Sulistyani *et al.,* (2022); Mulhim & Zaky (2023); Mylonas *et al.,* (2023); Kaur & Kaur (2022); Álvarez-Herrero (2023).
Contextual	1 (5,55)	Muhlis *et al.,* (2024)
Reception Comparison and Cache-cache Mode	1 (5,55)	Wang *et al.,* (2020)
Problem Solving	1 (5,55)	Harjono & Gunawan (2020)
HOTS	1 (5,55)	Kwangmuang *et al.,* (2021)
Blended Learning	1 (5,55)	Adam & Suprapto (2019)

Table 7. Not Integration Learning Strategy with Teaching Materials

Learning Strategy	Percentage (%)	References
STEM	2 (22,22)	Campbell *et al.,* (2022); Velázquez *et al.,* (2020)
Scientific Literacy	2 (22,22)	Jufrida *et al.,* (2019); Adnan *et al.,* (2021).

Table 8. Conducted Article Data

Writer's Name	Year	Method	Purpose	Findings
STEM Approach/Education (2)				
Campbell, C., Hobbs, L., Xu, L., McKinnon, J., & Speldewinde, C.	2022	Mixed Method	The aim is to understand how partnerships with industry can impact students, particularly in terms of their understanding of STEM and their interest in STEM careers and in line with pillar 4 of SDGs: Quality education, so that	The results showed that industry involvement in this project positively impacted the understanding and engagement of female students in STEM. They feel inspired by industry role models and feel that involvement in solving

Writer's Name	Year	Method	Purpose	Findings
			GALS is indispensable.	"real" problems helps them get more involved in STEM.
Velazquez, F. D. C., &; Rivas, F. L.	2020	Mixed Method	The research aims to merge ongoing education within school curricula, emphasizing the cultivation of environmental consciousness tied to Sustainable Development Goal 11. It evaluates students' attainment of specified learning goals and competencies pertinent to sustainable development.	The outcomes derived from the study are compelling, revealing elevated levels of awareness regarding the significance of sustainability, encompassing environmental, social, and economic dimensions fundamental to the principle of sustainability. These findings serve as a strong encouragement to persist in implementing the NEP within the classroom setting.
Teaching Materials (13)				
Teaching Materials for Scientific Literacy (5)				
Suprapto, N., Tafauliyati, T., &; Yanti, V. K.	2022	Research and Development	The research aims to create a high-quality and valid E-book for educational use. Specifically, it seeks to assess the validity of a scientific literacy-focused E-book on temperature and heat, analyzing aspects like media, materials, and language through the ADDIE framework.	Students' scientific literacy is low due to limited use of technology in physics education, as indicated by questionnaires. A newly developed scientific literacy E-book has a high validity score (90-95%) for educational use.
Asrizal, A., Annisa, N., Festiyed, F., Ashel, H., &; Amnah, R.	2023	Quasi-experimental	The primary objective of this study was to examine the influence of utilizing STEM-integrated digital	Overall, this study shows that the use of STEM-integrated PDTM in physics learning positively

Writer's Name	Year	Method	Purpose	Findings
			teaching materials (PDTM) on students' comprehension of concepts and the enhancement of new literacy skills. Researchers sought to ascertain whether the integration of STEM-based PDTM positively affected students' grasp of concepts and facilitated the cultivation of new literacy skills, encompassing areas such as data literacy, technological literacy, and human literacy.	impacts students' conceptual understanding and contributes to the improvement of new literacy, including data literacy, technological literacy, and human literacy. These results support the idea that STEM approaches in education can help students develop skills relevant to an increasingly connected and technology-driven world in education.
Widodo, W., Sudibyo, E., Suryanti., Sari, D. A. P., Inzanah, &; Setiawan, B.	2020	Pre-experiment Study	The main aim of this study is to assess the effectiveness of gadget-based interactive multimedia in enhancing the scientific literacy of Generation Z (Gen-Z) students in Indonesia.	Based on the results of data analysis, it can be concluded that gadget-based interactive multimedia that contain SSI on pressure concepts is effective in improving Gen-Z's scientific literacy. However, Gen-Z is not easily serviced or not easily satisfied using the developed gadget-based interactive multimedia
Subali, B., Ellianawati., Faizah, Z., & Sidiq, M.	2023	Quasi-experimental	The main objectives of this study were to investigate the potential of RE-STEM application in improving students' scientific literacy skills through ethnoscience and STEM approaches,	Generally, scientific literacy skills can improve by implementing ethno-STEM through RE-STEM App. The scientific learning methods (in app supported) also help teachers enhance students'

Writer's Name	Year	Method	Purpose	Findings
			involving Indonesian culture as a learning resource, as well as to understand its impact on students' ability to understand scientific concepts in the context of culture and ethnoscience.	scientific literacy in each aspect. Ethnoscience-learning integration embodied in several learning themes and related to traditional Indonesian culture is one of the significant factors in developing students' scientific literacy skills.
Muhlis., Raksun, A., Artayasam I. P., Hadiprayitno, G., &; Sukri, A.	2024	Research and Development	This study aims to develop context-based teaching materials and test the effectiveness of students' scientific literacy skills. This study also tries to understand whether the teaching materials are practical to use by teachers and whether they meet the criteria for validity.	Results put forward by researchers: • Teaching materials used by teachers in learning have not facilitated students to develop scientific literacy. • According to experts, the teaching materials that have been developed are valid and can be implemented. • Post hoc analysis showed that students' scientific literacy skills for aspects of interpreting data and evidence scientifically were higher compared to the other two aspects, evaluating and designing investigations scientific, as well as explaining phenomena scientific literacy of students.
Teaching Materials for Sustainability (4)				
Sulistyani, A. M., Prasetyo, Z. K., Hanum, F., &; Prasetyono, R. N.	2022	Research and Development	The main objective of this study is to develop an e-Book that can be used in science learning about	The data analysis and discussion shows the success of combining information technology,

Writer's Name	Year	Method	Purpose	Findings
			the environment in junior high schools, which is based on Indonesian local wisdom and aims to improve environmental care attitudes among students. In addition, this study also intends to validate the e-Book and assess the impact of its use on the development of environmentally caring character among students.	green science learning and local wisdom through the development of e-books. The success of e-book development is shown by the percentage of the three experts, namely 90.74%, indicating that the e-book based on Google sites in a local wisdom-oriented green science model is declared valid and feasible to use.
Muhlim, E. N, A., & Zaky, Y. A. M.	2023	Descriptive Causal Comparative	The study's objective was to examine the level of academic procrastination among secondary school students in the Kingdom of Saudi Arabia. It focused on comparing students utilizing continuous digital learning materials, specifically e-books, to those relying on printed books in traditional face-to-face learning settings.	Additionally, this study underscores that e-books, as a sustainable digital learning resource, align with the fourth Sustainable Development Goal, which aims to ensure quality education for all. E-books are highlighted as an eco-friendly and resilient knowledge source, contributing to sustainable educational practices.
Mylonas, G., Hofstaetter, J., Giannakos, M., Friedl, A., &; Koulouris, P.	2022	Quantitative	This study aims to quantify the influence of gamification as teaching materials/learning media in increasing awareness and sustainable behavior among school students, as well as to explore the extent to which this approach can be used in educational settings.	The GAIA Challenge employed basic game mechanics, incorporating elements like group competition, to actively involve participants. The study's outcomes indicate a successful achievement of research objectives. The data demonstrates significant engagement from students in the

Writer's Name	Year	Method	Purpose	Findings
				Challenge, emphasizing the efficacy of the competitive game mechanics used. In terms of promoting sustainability, post-activity surveys reflected increased awareness among students concerning pertinent issues. Educators also noted positive changes in their students' behavior following the activity.
Teaching Materials for Other Variables (4)				
Wang, J., Shimada, A., Oi, M., Ogata, H., &; Tabata Y.	2023	Quasi-experimental	This study investigates the impact of two learning modes, reception comparison and cache-cache comparison, on student learning performance and perception, considering variations in initial knowledge levels. It aims to enhance the learning experience in a VSSE environment and identify more effective strategies based on students' skill levels.	No significant correlation was observed between pre-test and post-test scores in both groups (experiment: r = -0.141, control: r = 0.127), preventing the use of ANCOVA. The "cache-cache comparison" group experienced higher stress using the e-book compared to the "reception comparison" group. Additionally, the "reception comparison" group felt more aligned with the learning mode than the "cache-cache comparison" group.
Harjono, A., Gunawan, G., Adawiyah, R., &; Herayanti, L.	2020	Quasi-experimental	This study aims to assess the effectiveness of interactive E-books in improving high school students' understanding of physics concepts, specifically focusing on	The interactive e-book, featuring videos, animations, audio, and practical problem-solving activities, proves effective in enhancing students' understanding and mastery

Writer's Name	Year	Method	Purpose	Findings
			"Rotational Dynamics and equilibrium of rigid bodies," and to evaluate their influence on students' cognitive domains.	of concepts. The results indicate a 'high criteria' improvement in equilibrium and 'medium criteria' in Rotational Dynamics. Mastery enhancement is observed across cognitive domains, with groups A and B showing 'high' improvement in C1 and C2, and 'medium' in C4 and C5. Notably, group A excelled in C3 and C5 with high improvement criteria, while group B achieved medium criteria in these domains
Kwangmuang, P., Jarutkamolpong, S., Sangboongraung, W., & Daungtod, S.	2021	Research and Development	This study's primary goal is to create a culturally contextualized "learning innovation" to enhance higher-order thinking skills among junior high school students in Thailand. The research focuses on designing and assessing the impact of these innovations, incorporating student perspectives.	The study's findings from five provinces in MRB, Thailand, reveal that the design and implementation of learning innovation significantly benefit junior high school students. The integrity test results indicate a substantial improvement in higher-order thinking skills, with 83% of students meeting success criteria. Positive student ratings emphasize the engaging and relevant content (X = 4.61), effective design (X = 4.28), and multimedia's information-conveying effectiveness (X = 4.02). Overall, the learning

Writer's Name	Year	Method	Purpose	Findings
				innovation is well-received, supporting enhanced learning experiences and skill.
Adam, A. S., &; Suprapto, N.	2019	Mixed Method	The study aims to develop Beboo, an inclusive physics E-book, to help 11th-grade high school students understand static fluids and the Pascal-Archimedes law. It includes bilingual support in English and Indonesian to cater to international school programs, ensuring broader accessibility.	A comprehensive e-Book named Beboo, inclusive of static fluids concepts, two virtual laboratories (u-pipe and hydraulic lift), bilingual features, student worksheets, sequence animations, videos, and a final self-assessment test, has been developed. Beboo underwent expert validations in four aspects, ranging from 72% to 95%, all categorized as "very good."
Scientific Literacy (2)				
Jufrida, J., Basuki, F. R., Kurniawan, W., Pangestu, M. D., &; Fitaloka, O.	2019	Quantitative – Correlation Types	This study aims to answer the question of whether there is a relationship or correlation between the level of scientific literacy of science and their learning achievement in science subjects. More specifically, this study wanted to determine the extent to which students' scientific literacy had an impact on student achievement in science subjects at Public Junior High School in Jambi.	The findings revealed an average score of 33.7 for scientific literacy (categorized as low) and an average score of 21.5 for science study results (classified as very low). The results of the correlation test showed a significance value of 0.000, which is less than 0.05. Consequently, the null hypothesis (Ho) was rejected, indicating a significant relationship between scientific literacy and students' science learning outcomes in the junior high schools across

Writer's Name	Year	Method	Purpose	Findings
				the Jaluko subdistrict in Jambi, Indonesia.
Adnan., Mulbar, U., Sugiarti., & Bahri, A.	2021	Quantitative	This study aims to understand the extent of students' science literacy skills in South Sulawesi, especially in biology learning at junior high school, and provide guidelines and recommendations to improve students' science literacy at the junior high school level.	Junior high school students in South Sulawesi show low scientific literacy in biology. Only 17.02% understand inquiry methods, and 36.23% can handle quantitative data. This highlights the need for immediate improvements in biological science education.

The study's findings highlight three distinct approaches employed in the execution of STEM or STEAM education within Indonesia, as depicted in Figure 5. The integrated STEM approach coupled with teaching materials has found widespread application in overseas science learning implementations, as indicated in Figure 5. Integrating STEM education and teaching materials into science learning via diverse learning models enables students to develop competencies aligned with learning objectives. Furthermore, the adoption of interactive teaching materials is prevalent in overseas settings, particularly in junior high schools and senior high schools, with a notable emphasis on secondary school implementation, as illustrated in Figure 6. Additionally, the integration of STEM and teaching materials can be harmonized with various learning strategies, detailed in Table 6. Notably, STEM education consistently correlates with specific research themes.

Predictors of Scientific Literacy and Sustainability Awareness

This section delves deeply into the intricate web of variables influencing scientific literacy and sustainability awareness, presenting a nuanced understanding of previous research findings and exploring diverse explanatory approaches. The research systematically identifies pivotal predictors contributing to the enhancement of scientific literacy and sustainability awareness among students. Several influential factors shape the landscape of scientific literacy:

Technology Integration, Adequate Teaching Materials, and Facility Availability

The inadequacy of integrating technology into science education, particularly in the field of science, alongside a shortage of teaching materials, emerges as a key factor contributing to low levels of scientific literacy (Jufrida et al., 2019; Adnan et al., 2021; Suprapto et al., 2022; Kaur & Kaur, 2022). This deficiency, consistently emphasized in various studies, extends specifically to physics education, exacerbating the hurdles in achieving scientific

literacy. Internal factors, such as a lack of facilities dedicated to science literacy training, further compound these challenges, underscoring the multifaceted nature of the issue (Jufrida et al., 2019; Suprapto et al., 2020).

Interactive Learning Media

External factors, specifically the limited use of interactive learning media, emerge as a substantial obstacle negatively impacting science literacy skills. This highlights the importance of dynamic and engaging instructional approaches to foster effective learning (Jufrida et al., 2019; Suprapto et al., 2020).

Development of Comprehensive Science Literacy E-Books and Multimedia

Addressing these multifaceted challenges, scholars advocate for the development of science literacy E-books and interactive multimedia. This initiative is not merely a technological upgrade but a holistic approach, supported by comprehensive learning tools such as syllabi, lesson plans, worksheets, and assessment sheets. These tools aim to provide a rich and immersive learning experience (Widodo et al., 2020; Adnan et al., 2021; Suprapto et al., 2022).

Innovative Teaching Strategies and Experimental Methods

Educators are encouraged to embrace inventive teaching approaches, placing a dedicated emphasis on enhancing science literacy. Notably, Adam & Suprapto (2021), Asrizal et al. (2023), and Muhlis et al. (2024) emphasize the importance of incorporating hands-on experimental methods and virtual experiments. These methods are instrumental in fostering higher-level cognitive processes and promoting contextual comprehension. This underscores the dynamic and evolving nature of effective pedagogy.

STEM Approach in Education

In the quest to enhance students' science literacy and instill environmental awareness in alignment with the Sustainable Development Goals (SDGs), the integration of STEM principles emerges as a pivotal and recognized strategy. This strategic integration, as highlighted by Velázquez & Rivas (2020), Campbell et al. (2022), Asrizal et al. (2023), and Subali et al. (2023), signifies a holistic approach that goes beyond traditional subject boundaries. This approach is designed to cultivate a comprehensive understanding of scientific concepts and their practical applications in the real world.

Multimedia-Rich E-Books with Bilingual Elements

As the educational terrain undergoes a transition from conventional textbooks to electronic books (e-books), there is a growing emphasis on advocating for the creation of multimedia-enriched e-books with bilingual features. Findings from studies by Adam & Suprapto (2021) and Wang et al. (2023) underscore the significance of inclusivity and broader access. This shift intends not only to cater to diverse learners but also to align with international educational initiatives.

Game-Based Teaching Materials and Environmental Education Activities

Teaching materials that incorporate game-based elements and integrated environmental education activities, exemplified by initiatives like #ALCada22, demonstrate their effectiveness in imparting sustainability concepts and raising students' environmental awareness. Contributions from Kwangmuang et al. (2021), Mylonas et al. (2022), and Álvarez-Herrero (2023) emphasize the value of gamification and real-world activities in enriching science literacy. The documented success of gadget-based interactive multimedia, alongside the application of the Socio-Scientific Issues approach as highlighted by Widodo et al. (2020), signals a notable shift towards immersive, technology-driven learning experiences.

Continuous Innovation in Teaching Materials and Methods

The effectiveness of electronic teaching materials, especially those incorporating innovative methodologies such as STEM, highlights the essential role of continuous innovation within the teaching community. This perpetual evolution is critical for the development and integration of interactive materials into the science learning process. Beyond embracing technological advancements, it signifies a pedagogical shift towards adaptive and student-centered learning approaches. The ongoing innovation in both teaching materials and methods serves as a cornerstone in addressing the dynamic challenges and opportunities in science education. This approach not only enhances the overall learning experience but also equips students to navigate a swiftly changing educational landscape and prepares them for the scientific and environmental challenges of the future.

Discussion

This study aimed to conduct a literature review encompassing publications between 2019 and 2024 within SINTA 1 and quartiles Q1-Q4, focusing on STEM Education and teaching materials. The goal was to comprehend the theoretical and practical advancements, conceptual evolution, and varied factors explored in the literature concerning this subject.

The content derived from numerous studies, despite presenting a few areas with conflicting outcomes, was organized based on the PRISMA model. This systematic approach illustrated the potential to uncover novel factors contributing to STEM education and teaching materials. These insights aimed to offer a comprehensive understanding of the phenomenon of low scientific literacy and sustainability awareness, addressing it holistically by considering diverse factors influencing the process.

Topics of STEM Education and Teaching Materials Research

STEM and teaching materials research has increased from year to year (See Fig. 2). Research in STEM and teaching materials has witnessed a steady increase over the years, delving into the challenges surrounding students' scientific literacy. Studies attribute low achievement to the underutilization of technology and insufficient teaching materials, particularly in physics (Jufrida et al., 2019; Adnan et al., 2021; Suprapto et al., 2022; Kaur &

Kaur, 2022). Both internal and external factors, such as a lack of facilities and interactive learning media, are identified as contributors to poor science literacy skills (Jufrida et al., 2019; Suprapto et al., 2020).

In response to these challenges, the research advocates for the development of science literacy E-books and multimedia, supported by comprehensive learning tools (Widodo et al., 2020; Adnan et al., 2021; Suprapto et al., 2022). Diverse teaching strategies, including hands-on experiments and virtual experiments, are encouraged to enhance science and new literacy (Asrizal et al., 2023; Muhlis et al., 2024).

The integration of a STEM approach is recognized as an effective strategy to improve new literacy and sustainability awareness (Velázquez & Rivas, 2020; Campbell et al., 2022; Asrizal et al., 2023; Subali et al., 2023). Studies emphasize the significance of Sustainable Development Goals (SDGs), showing increased awareness of sustainability, including practice, behavioral, and emotional awareness among students (Velázquez & Rivas, 2020; Kaur & Kaur, 2022). The shift from traditional textbooks to e-books is noted, emphasizing the need for multimedia-rich content and bilingual elements for wider access and alignment with international programs (Adam & Suprapto, 2021; Suprapto et al., 2022; Wang et al., 2023).

Gadget-based interactive multimedia and the Socio-Scientific Issues approach are highlighted as effective tools in improving science literacy, with positive student responses (Widodo et al., 2020). Game-based teaching materials and integrated environmental education activities further contribute to students' awareness of environmental and sustainability issues (Kwangmuang et al., 2021; Mylonas et al., 2022; Álvarez-Herrero, 2023).

The research underscores the success of innovative electronic teaching materials, particularly those employing the STEM approach, in enhancing students' science literacy and awareness of sustainable issues. The findings encourage teachers to embrace innovation in creating and implementing interactive teaching materials in the science learning process. Trends in STEM education and teaching materials in terms of research methods that dominate used in overseas are experimental, research and development, and mixed methods (See Table 3 and Table 8).

STEM Education and Teaching Materials on Science Learning Implementation

The study emphasizes the crucial role played by STEM (Science, Technology, Engineering, and Mathematics) education and innovative teaching materials in enhancing students' scientific literacy and sustainability awareness. The research findings uncover a noteworthy deficiency in scientific literacy among students, linked to inadequate technology utilization, particularly in physics education, and a lack of sufficient teaching materials (Jufrida et al., 2019; Adnan et al., 2021; Suprapto et al., 2022; Kaur & Kaur, 2022). Both internal and external factors, such as limited facilities and a shortage of interactive learning media, contribute to the challenges in science literacy (Jufrida et al., 2019; Suprapto et al., 2020). To address these challenges, the study advocates for the development of science literacy E-books and interactive multimedia, complemented by comprehensive learning tools (Widodo et al., 2020; Adnan et al., 2021; Suprapto et al., 2022). Teachers are encouraged to employ diverse strategies, including hands-on experiments and virtual experiments, to foster higher-level thinking and contextual

understanding (Adam & Suprapto, 2021; Muhlis et al., 2024). The integration of a STEM approach values emerges as a potent strategy to improve both new literacy and sustainability awareness (Velázquez & Rivas, 2020; Campbell et al., 2022; Asrizal et al., 2023). The gradual shift from traditional textbooks to e-books, enriched with multimedia elements, is highlighted for its positive impact (Suprapto et al., 2022; Wang et al., 2023). Various studies showcase the effectiveness of interactive e-books, gadget-based multimedia, game-based teaching materials, and integrated environmental education activities in enhancing science literacy and sustainability awareness (Harjono et al., 2020; Widodo et al., 2020; Mylonas et al., 2022; Kwangmuang et al., 2021; Álvarez-Herrero, 2023). The success of these electronic teaching materials, particularly those incorporating STEM approach, underscores their significance in the current educational landscape, promoting a call for increased innovation among teachers in crafting interactive learning experiences for students.

A Comprehensive Approach through STEM Integration, Multimedia E-Books, and Game-Based Teaching Material

This research emphasizes the urgency of enhancing students' scientific literacy, which currently stands at a low level due to the insufficient utilization of technology, particularly in the context of science education, and the lack of teaching materials. To address these challenges, a versatile solution is proposed, emphasizing the integration of STEM principles into teaching materials (Subali et al., 2023; Asrizal et al., 2023).

It is recommended to introduce science literacy E-books or interactive multimedia enriched with various media elements, including text, images, diagrams, sound effects, music, videos, and animations. This approach aims not only to create an interactive and effective learning experience but also to design a stimulating learning environment. Moreover, the integration of bilingual elements is suggested to support broader access and alignment with relevant international programs (Widodo et al., 2020; Adnan et al., 2021; Adam & Suprapto, 2021; Suprapto et al., 2022).

Based on findings from studies on energy and sustainability education, game-based teaching materials are highlighted as valuable tools for conveying sustainability concepts to students. This approach not only enhances students' attitudes and awareness of sustainability issues but also immerses them in a holistic understanding of economic, environmental, and social aspects, and positive student responses highlight the potential of this integrated method in engaging and enhancing comprehension, particularly in abstract and complex scientific topics. This approach contributes to fostering a sense of responsibility and care toward environmental concerns (Kwangmuang et al., 2021; Mylonas et al., 2022; Álvarez-Herrero, 2023).

Integrating sustainability education into teaching materials has been shown to enhance students’ awareness across various dimensions of sustainability, including practice, behavioral, and emotional aspects (Velázquez & Rivas, 2020; Kaur & Kaur, 2022). E-books, serving as a sustainable digital learning resource, align with the fourth Sustainable Development Goal, focusing on quality education. Their eco-friendly and enduring nature makes them a valuable source of knowledge, fostering sustainability in educational practices.

The development of electronic teaching materials, specifically E-books, utilizing a green science approach, is encouraged. This approach, supported by studies (Sulistyani et al., 2022; Kaur & Kaur, 2022; Mulhim & Zaky, 2023), positively impacts students' environmental consciousness. It emphasizes the significance of integrating environmental themes into science education, contributing to the cultivation of students' environmental care values.

This comprehensive strategy aims to revolutionize science education by uniting STEM principles, interactive multimedia resources, and innovative game-based teaching methods. The expectation is that this combination will shape higher levels of scientific literacy, deepen students' understanding of science, and stimulate their interest in exploring further realms of knowledge. Thus, these measures are anticipated to mold a generation of students ready to face the complex challenges of the modern world.

Promotion of STEM Approach in Education

Highlighting the importance of the STEM approach, especially in physics education, is acknowledged as a valuable strategy for enhancing students' science literacy. This approach not only enhances scientific comprehension but also integrates sustainable education, promoting environmental awareness aligned with Sustainable Development Goals (SDGs) (Velázquez & Rivas, 2020; Campbell et al., 2022; Asrizal et al., 2023). In essence, the incorporation of STEM principles into teaching materials serves as a comprehensive strategy to tackle challenges in students' scientific literacy. This approach not only underscores technological advancements but also integrates sustainability education, creating a well-rounded learning environment that aligns with current educational needs. The success of various electronic teaching materials developed with innovative approaches, particularly STEM, underscores their significance in advancing science literacy and sustainability awareness among students. This research encourages educators to embrace a more innovative and interactive approach in crafting teaching materials for the science learning process.

STEM and Teaching Materials Associated Theme

The text emphasizes STEM education and innovative teaching materials to address scientific literacy challenges and promote sustainability awareness. It identifies inadequate technology use and teaching materials as contributors to low literacy, emphasizing the need for E-books and multimedia. Urgent calls are made for their development, with encouragement for teachers to adopt diverse strategies. STEM integration and the shift to multimedia-rich e-books are highlighted, along with positive impacts of interactive multimedia and game-based teaching. The success of electronic teaching materials underscores their role in enhancing science literacy and sustainability awareness, urging continuous teacher innovation.

Future STEM Education and Teaching Materials Research Recommendations

Recommendations for future research related to these topics are proposed, including: (1) Investigate and develop innovative teaching approaches that integrate STEM and Education for Sustainable Development (ESD) to

enhance students' science literacy and awareness of sustainable issues; (2) Conduct research to assess the impact of interactive E-books, particularly those incorporating multimedia elements and bilingual features, on students' understanding of science materials and abstract concepts; (3) Explore the effectiveness of game-based approaches in teaching sustainability concepts, as suggested by studies on game-based teaching materials in energy and sustainability education; and (4) Encourage research on strategies to enhance teacher innovation in creating and implementing interactive teaching materials in the science learning process, particularly those aligned with STEM and ESD principles.

Conclusion and Future Research

The trend in STEM education and teaching materials research overseas over the past five years predominantly revolves around experimental methods, particularly in secondary school science subjects. Key themes such as critical thinking skills, scientific literacy, and learning outcomes are dominant in STEM education studies. The findings suggest that STEM education significantly fosters 21st-century learning skills.

Teaching materials are designed to enhance classroom learning, formulated as science-based materials to adapt to evolving curricular changes. It is imperative to continue evolving the learning process, striving to create innovative learning products that address societal educational needs. Implementing STEM approaches in teaching materials innovation, as highlighted in the results and discussions, is crucial.

However, it's essential to conduct research beyond statistical analyses, exploring factors like cultural context and perceptions of education's value. Investigating novel avenues and challenges faced by students in adapting to university life is vital. Dropout intention, often viewed deterministically, needs a more comprehensive approach considering the entire educational journey.

The development of scientific literacy E-books or interactive multimedia, supported by learning tools like syllabi, lesson plans, and assessments, has been advocated by various studies. Moreover, studies emphasize the potential of science learning in enhancing scientific literacy, new literacy, and sustainability awareness through the STEM approach. This approach integrates sustainable education, focusing on environmental awareness aligned with Sustainable Development Goals (SDGs). Recognizing that internal school strategies are insufficient, influencing educational policies becomes crucial to enhancing overall education quality and preventing educational issues.

Future studies should aim for a holistic understanding by integrating STEM education with technology-based teaching materials, Environmental and Sustainable Development (ESD), and enhancing 21st-century learning skills. Such research endeavors aim to reinforce students' persistence and successful academic completion. This critical analysis review provides theoretical insights, exploring low scientific literacy, limited use of STEM approaches, and the innovation of interactive teaching materials. By delving into causative factors, identifying variables, and categorizing them based on existing research, this review aims to stimulate new perspectives for advancing theoretical and practical aspects. Understanding the current scientific knowledge while exploring new variables can pave the way for more comprehensive future explorations.

Limitation

To ensure the thoroughness of the study, it is advisable to expand the search scope of articles in the database from 2019 to 2024. This broader timeframe encompasses recent developments and allows for a more up-to-date and comprehensive examination of research in STEM education, teaching materials, scientific literacy, and sustainability awareness. Including articles published during this extended period will provide a nuanced understanding of the evolving landscape. Moreover, conducting a focused search for emerging trends, innovative approaches, and recent advancements in these areas will contribute valuable insights to the study, enhancing its relevance and depth.

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