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The Integration of Digital Technology into Physics Education for Sustainable Development: A Literature Review

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ABSTRACT

Objective: *This study aims to identify various forms of digital technology used in physics learning to support sustainable education, analyze how these technologies are integrated into the physics learning process, and examine the challenges and opportunities of implementing technology-enhanced physics education for sustainable development.* ***Method:*** *This study employed a qualitative approach, using a literature review to examine prior research on technology-enhanced physics education. The dataset consisted of 20 journal articles published between 2017 and 2025, retrieved from Scopus and Google Scholar.* ***Results:*** *The findings indicate that various forms of digital technology, such as simulations, virtual laboratories, augmented reality (AR), virtual reality (VR), and digital learning resources, are widely used in physics education. These technologies support the visualization of abstract physics concepts, increase students' engagement and motivation, and improve conceptual understanding and problem-solving skills. The reviewed studies also show that digital technologies are frequently integrated with pedagogical approaches such as problem-based learning, flipped classroom learning, and scaffolding strategies to create more interactive and student-centered learning environments. In addition, several challenges were identified, including limitations in technological infrastructure and teachers' readiness to integrate digital tools in teaching practices.* ***Novelty:*** *This study contributes to the existing literature by synthesizing recent research on integrating digital technology into physics education for sustainable development. It identifies the types of digital technologies, their pedagogical integration, and the challenges and opportunities associated with their implementation, providing insights for future research and the development of more effective technology-enhanced physics learning.*

INTRODUCTION

The development of digital technology has brought significant changes across various sectors of life, including education. Digital transformation in education encourages the utilization of various technologies to enhance the quality of learning, expand access to learning resources, and create more interactive and flexible learning experiences (Bond et al., 2021; OECD, 2021). The integration of digital technology in learning has also become an important strategy for addressing the demands of 21st-century competencies, such as critical thinking, problem-solving, collaboration, and digital literacy (Haleem et al., 2022; UNESCO, 2023). In the context of science education, digital technologies such as interactive simulations, virtual laboratories, augmented reality, and computer-based visualizations have been widely used to help students understand complex scientific concepts (Makransky & Petersen, 2021; Radianti et al., 2020). Therefore, the use of technology in science education is considered an effective approach to improving the quality of the learning process in the digital era. Beyond improving the quality of learning, digital technology is expected to foster students' digital competence, which has become an essential component of contemporary science education (Ilomäki, 2023).

On the other hand, education is currently facing global challenges related to sustainable development. The Sustainable Development Goals (SDGs) agenda positions education as a key factor in promoting transformation toward a more sustainable society (UNESCO, 2021). The concept of Education for Sustainable Development (ESD) emphasizes the importance of education in equipping students with the knowledge, skills, and values needed to address global issues such as climate change, energy crises, and environmental degradation (Leal Filho et al., 2021; UNESCO, 2021). Education oriented toward sustainability focuses not only on knowledge acquisition but also on developing students' ability to understand the relationships among science, technology, the environment, and society (Rieckmann, 2021). Thus, integrating sustainability concepts into the learning process has become an essential aspect of future educational development.

In the context of science education, particularly physics, the integration of sustainability concepts holds significant potential for development. Various concepts in physics, such as energy, waves, and renewable energy technologies, are closely related to sustainability issues and technological advancement (Prayogi & Verawati, 2024). In addition, physics learning plays an important role in developing students' scientific thinking, problem-solving abilities, and scientific literacy (OECD, 2021; Schindler et al., 2021). The use of digital technology in physics learning can help students visualize abstract phenomena and explore scientific concepts more deeply through simulations and virtual experiments (Makransky & Petersen, 2021; Radianti et al., 2020). Therefore, integrating technology into physics education has the potential to effectively support the implementation of sustainable education.

However, various international reports indicate that the use of technology in education still faces several challenges. The Global Education Monitoring Report shows that approximately 40% of schools worldwide still lack adequate access to digital technology for learning purposes (UNESCO, 2023). Furthermore, OECD surveys indicate that not all educators possess sufficient digital competence to effectively integrate technology into teaching practices (OECD, 2021). Similar findings have been reported by Tondeur et al. (2023), who emphasized that teachers' professional development and pedagogical readiness remain essential factors for successful technology integration. In the context of science learning, several studies also show that technology use is often limited to simple presentation media and has not been optimally utilized to support deeper exploration of scientific concepts (Anandita et al., 2024; Schindler et al., 2017). Therefore, further research is increasingly needed to understand how digital technology can be effectively integrated into physics education to support Education for Sustainable Development (ESD) through more inclusive, flexible, and learner-centered learning environments (Haleem et al., 2022; UNESCO, 2023). Digital transformation in education also requires schools to strengthen their digital capacity, including technological infrastructure, institutional support, and teachers' readiness to integrate technology effectively into teaching and learning (Timotheou et al., 2023).

On the other hand, research in recent years has shown increasing attention to the use of technology in science and physics education. Various innovations such as interactive simulations, virtual laboratories, and STEM-based learning media have been developed to improve the quality of physics education (Tarigan et al., 2024). Studies also indicate that technology integration in learning can enhance conceptual understanding, student engagement, and problem-solving skills (Makransky & Petersen, 2021; Bond et al., 2021). Moreover, technology enables students to connect scientific concepts to real-world sustainability problems (Alhusni et al., 2025; Leal Filho et al., 2021). Several literature reviews have also examined the use of digital technology in physics education. Faresta et al. (2024) reviewed the utilization of various digital technologies in physics education and discussed their implications for future physics learning. Meanwhile, Prayogi and Verawati (2024) reviewed the contribution of digital technology to the achievement of the Sustainable Development Goals (SDGs) in physics education. Building on these studies, the present review synthesizes empirical studies on the implementation of digital technology in physics learning by identifying the types of technology used, their integration into learning practices, and the educational outcomes reported in relation to sustainable education.

Based on the discussion above, the integration of digital technology in physics education has significant potential to support the implementation of Education for Sustainable Development. However, a comprehensive literature review is still needed to understand the development of research related to the use of technology in physics education that supports sustainable education. Therefore, this study aims to: 1) identify various forms of digital technology used in physics learning to support sustainable education, 2) analyze how these technologies are integrated into the physics learning process, and 3) examine the challenges and opportunities in implementing technology-enhanced physics education to support sustainable education.

RESEARCH METHOD

This study employed a qualitative approach, using a literature review, to examine prior research on technology-enhanced physics education and its support for sustainable development. A literature review is a research method used to systematically identify, analyze, and synthesize existing studies in order to provide a comprehensive understanding of a particular research field (Snyder, 2019; Xiao & Watson, 2019). In educational research, literature reviews are widely used to summarize existing knowledge, identify research gaps, and provide directions for future studies (Snyder, 2019; Paul & Criado, 2020). Through this approach, the present study examines prior findings on the integration of digital technologies in physics education and their contribution to sustainable education.

The procedure of this study followed several stages commonly used in literature review research, including literature identification, screening and selection of articles, critical review and data extraction, synthesis of findings, and concluding (Fink, 2019; Snyder, 2019; Xiao & Watson, 2019). These stages aim to ensure that the literature review process is conducted systematically, transparently, and in a manner that can be replicated by other researchers (Snyder, 2019). The overall research procedure adopted in this study is illustrated in Figure 1, which presents the research design used in this literature review.

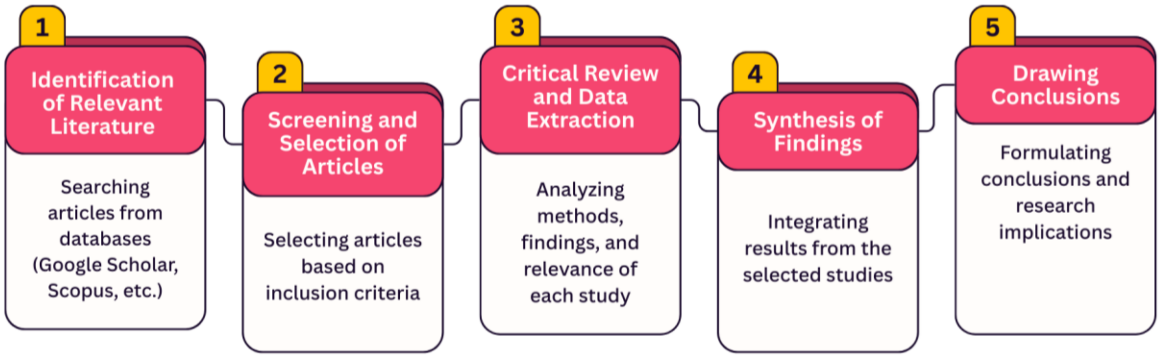

Figure 1. Flow of research methods

The first stage involved identifying relevant literature via Google Scholar and Scopus, which provide access to peer-reviewed publications in education, science education, and educational technology (Xiao & Watson, 2019). The search process used keyword combinations related to the research topic, including "technology-enhanced learning," "physics education," "digital technology in science education," and "education for sustainable development." The retrieved studies were manually screened for relevance to the objectives of this review. Following the screening process, a final dataset consisting of 20 peer-reviewed journal articles published between 2017 and 2025 was selected for further analysis. Using multiple keywords helped broaden the scope of the search and minimize the possibility of overlooking relevant studies (Snyder, 2019; Paul & Criado, 2020).

After the identification process, the retrieved studies were screened and selected based on predetermined inclusion and exclusion criteria. The inclusion criteria were: (1) peer-reviewed journal articles, (2) published between 2017 and 2025, (3) written in English, (4) focused on the implementation of digital technology in physics education, and (5) reporting findings related to learning processes or outcomes that support sustainable education (Fink, 2019). Studies were excluded if they were conference papers, book chapters, theses, non-English publications, or unrelated to the implementation of digital technology in physics education.

The selected articles were then analyzed through a critical review and data extraction process. Information extracted from each study included the publication year, research objectives, research methodology, types of digital technology, pedagogical approaches, and key findings (Fink, 2019; Xiao & Watson, 2019). The extracted data were subsequently synthesized to identify patterns and themes regarding the implementation of digital technology in physics learning and its contribution to sustainable education (Paul & Criado, 2020).

The synthesized findings were organized into three main themes: (1) forms of digital technology used in physics learning, (2) the integration of digital technology into physics learning, and (3) the challenges and opportunities of technology-enhanced physics education in supporting sustainable development. Finally, conclusions were drawn to highlight the contributions of technology-enhanced physics education in supporting sustainable development and to identify potential directions for future research (Snyder, 2019).

RESULTS AND DISCUSSION

Results

This study reviewed 20 research articles on the integration of digital technology in physics education. The reviewed studies were selected from reputable journals and conference proceedings focusing on physics education and technology-enhanced learning. The analysis aims to identify the types of digital technologies used in physics learning and to understand how these technologies influence learning outcomes and students' engagement.

Previous studies indicate that digital technologies such as simulations, augmented reality, virtual reality, and digital learning media can enhance the effectiveness of physics learning by facilitating visualization of abstract concepts and supporting interactive learning environments (Lintangesukmanjaya et al., 2025; Maulidah & Prima, 2018; Yunzal & Casinillo, 2020). Furthermore, immersive technologies allow students to explore physical phenomena in more meaningful ways through digital interaction and experimentation (Johnson-Glenberg & Megowan-Romanowicz, 2017; Strzys et al., 2018). To provide a clearer overview of the reviewed studies, the characteristics and main findings of the selected articles are summarized in Table 1.

Table 1. Summary of reviewed studies on technology-enhanced physics education

No.	Document Title	Authors (Year)	Method	Technology Type	Results
1.	Exploring Technology-Driven Simulations in Practical Physics: Insights into Mechanical Measurements Concept	Kade et al., 2024	Experimental	Simulation technology	The use of simulation technology in practical physics learning improved students' understanding of mechanical measurement concepts and helped them analyze experimental data more accurately.

No.	Document Title	Authors (Year)	Method	Technology Type	Results
2.	Integrating Earthquake Technologies into Physics Learning for Education for Sustainable Development: A Systematic Literature Review	Alhusni et al., 2025	Systematic literature review	Earthquake technology simulation	The study found that integrating disaster-related technologies into physics learning can improve contextual understanding of physical concepts while promoting awareness of sustainable development issues.
3.	Virtual Physics Experiments: Transforming Science Process Skills through Digital Integration	Syukriah et al., 2025	Quasi-experimental	Virtual physics experiment	Digital experiments significantly improved students' science process skills, including observing, analyzing, and interpreting experimental results.
4.	Effect of Physics Education Technology (PhET) Simulations: Evidence from STEM Students' Performance	Yunzal & Casinillo, 2020	Quasi-experimental	PhET simulation	Students who used PhET simulations achieved higher academic performance and demonstrated better conceptual understanding compared to students who learned through conventional instruction.
5.	The Effect of Problem Based Learning Model Assisted by PhET Simulation on	Rianti et al., 2024	Experimental	PhET & Problem Based Learning	The integration of PhET simulations with problem-based learning improved students' conceptual

No.	Document Title	Authors (Year)	Method	Technology Type	Results
	Understanding Physics Concepts				understanding and their ability to solve physics-related problems.
6.	Using Physics Education Technology as Virtual Laboratory in Learning Waves and Sounds	Maulidah & Prima, 2018	Experimental	Virtual laboratory	Virtual laboratory activities helped students visualize wave and sound phenomena more clearly and improved their conceptual comprehension of the topic.
7.	Virtual Reality Technology in Physics Learning: Possibility, Trend, and Tools	Budi et al., 2021	Systematic literature review	Virtual Reality (VR) technology	The study revealed that virtual reality has strong potential in physics education by increasing students' engagement, motivation, and learning experience. The review also showed a growing research trend in VR-based physics learning and identified commonly used devices such as HTC Vive.
8.	The Application of Augmented Reality (AR) in Physics Education: A Case Study on Optics Material	Basir & Uding, 2025	Case study	Augmented Reality	AR-based learning media helped students understand optical concepts by providing interactive three-dimensional visualizations of physical phenomena.

No.	Document Title	Authors (Year)	Method	Technology Type	Results
9.	The Effectiveness of a 3D-Virtual Reality Learning Environment (3D-VRLE) on Students' Achievement and Motivation towards Physics Learning	Al Amri et al., 2020	Experimental	3D Virtual Reality	The VR learning environment significantly increased students' motivation and learning achievement in physics classes.
10.	Physics Holo.lab Learning Experience: Using Smartglasses for Augmented Reality Labwork to Foster the Concepts of Heat Conduction	Strzys et al., 2018	Experimental	AR smartglasses laboratory	Augmented reality laboratory activities helped students better understand heat conduction concepts through immersive visualization and hands-on interaction.
11.	Embodied Science and Mixed Reality: How Gesture and Motion Capture Affect Physics Education	Johnson-Glenberg & Megowan-Romanowicz, 2017	Experimental	Mixed reality learning	Gesture-based mixed reality learning improved students' conceptual understanding and supported embodied learning experiences in physics education.
12.	Augmented Reality in Physics Education: A Tool for Intellectual Learning	Arymbekov & Turekhanova, 2025	Experimental	Augmented Reality	Augmented reality learning significantly improved students' intellectual engagement and conceptual

No.	Document Title	Authors (Year)	Method	Technology Type	Results
					comprehension in physics topics.
13.	Development of Augmented Reality-Based Physics Learning Media on Magnetic Field	Sholeh et al., 2024	Research & Development	AR learning media	The developed AR-based physics learning media improved students' ability to visualize magnetic field concepts and enhanced their conceptual understanding.
14.	Textbooks Equipped with Augmented Reality Technology for Physics Topic in High School	Bakri et al., 2019	Development	AR-integrated textbook	Physics textbooks equipped with AR technology helped students visualize abstract physics concepts and increased their interest in learning.
15.	Augmented Reality in Physics Learning: Opportunities to Improve Teacher and Student Interaction in Online Learning	Nurhasanah et al., 2021	Experimental	Augmented Reality learning system	The implementation of AR technology improved interaction between teachers and students and supported more engaging online physics learning.
16.	Physics E-Book with Augmented Reality to Improve Students' Interest in Physics	Novita, 2023	Development	AR-based physics e-book	The AR-based e-book increased students' learning interest and supported interactive exploration of physics concepts.
17.	Development of Interactive Learning Media Based on	Hidayah et al., 2025	Development	Augmented simulation using PhET	The developed interactive simulation media improved students'

No.	Document Title	Authors (Year)	Method	Technology Type	Results
	Augmented Simulation Using PhET for Magnetic Field Material				understanding of magnetic field concepts and supported active learning.
18.	Students' Conceptual Understanding in Modified Flipped Classroom Approach: An Experimental Study in Junior High School Science Learning	Putri et al., 2020	Experimental	Technology-supported flipped classroom	The flipped classroom approach supported by digital technology improved students' conceptual understanding and participation in learning activities.
19.	High School Physics Student Worksheets Assisted by Augmented Reality: Enhancing Problem Solving Skills	Denny et al., 2023	Development	AR-assisted worksheet	AR-based worksheets enhanced students' problem-solving abilities and encouraged active engagement in physics learning.
20.	The Integration of Scaffolding and Augmented Reality in Physics Learning	Karim et al., 2025	Experimental	AR + scaffolding learning	The integration of augmented reality with scaffolding strategies significantly improved students' conceptual understanding and learning confidence.

The results of the reviewed studies indicate that various digital technologies have been implemented in physics learning. Simulation technologies and virtual laboratories are commonly used to support experimental learning and conceptual visualization (Maulidah & Prima, 2018; Kade et al., 2024). In addition, immersive technologies such as augmented reality and virtual reality provide interactive learning environments that enhance students' motivation and conceptual understanding (Al Amri et al., 2020; Arymbekov & Turekhanova, 2025).

Several studies also highlight the role of digital learning materials, including AR-based textbooks, e-books, and worksheets, which help students access learning resources more flexibly and support independent learning (Bakri et al., 2019; Novita, 2023; Denny et al., 2023). Overall, the findings demonstrate that integrating technology into physics education can enhance students' engagement, conceptual understanding, and problem-solving skills.

Discussion

Forms of Digital Technology Used in Physics Learning

The findings of this study reveal that various forms of digital technology are used in physics education, including simulations, virtual laboratories, augmented reality, virtual reality, and digital learning resources. Simulation technologies are among the most frequently used tools because they allow students to visualize physical phenomena that are difficult to observe directly in real laboratory settings (Yunzal & Casinillo, 2020; Kade et al., 2024). Through simulation-based environments, students can manipulate variables and observe the effects of physical processes interactively.

Augmented reality and virtual reality technologies also play a significant role in enhancing physics learning experiences. These technologies enable students to interact with three-dimensional representations of physical concepts, such as magnetic fields, optics, and heat conduction (Strzys et al., 2018; Arymbekov & Turekhanova, 2025). Immersive technologies create more engaging learning environments that help students understand complex concepts through visualization and interaction.

Furthermore, digital learning materials such as AR-based textbooks, e-books, and worksheets support flexible learning and improve accessibility of physics education (Bakri et al., 2019; Novita, 2023). These resources align with the principles of sustainable education, which emphasize the use of innovative learning tools to support lifelong learning and access to knowledge.

The reviewed studies also show that different digital technologies are used for distinct learning purposes. Simulation-based technologies, such as PhET and virtual laboratories, were the most frequently applied because they enable students to visualize abstract concepts and investigate physical phenomena through interactive experimentation. Similar findings were reported by Makransky and Petersen (2021), who explained that simulation-based learning supports students' conceptual understanding by providing opportunities to explore scientific concepts interactively. In contrast, augmented reality was more commonly used to support the visualization of three-dimensional concepts. In contrast, virtual reality was mainly applied to create immersive learning experiences that increase students' engagement and motivation (Radianti et al., 2020). These findings suggest that the selection of digital technology should consider the characteristics of the learning objectives and physics content rather than focusing solely on technological innovation. Recent studies also indicate that digital technologies provide greater opportunities for conducting virtual experiments and inquiry-based learning, particularly when access to conventional laboratory facilities is limited (Lahme et al., 2023).

Integration of Technology in Physics Learning

The reviewed studies show that digital technologies are often integrated with various pedagogical approaches, such as problem-based learning, flipped classroom learning, and scaffolding strategies. For example, integrating PhET simulations with problem-based learning can enhance students' conceptual understanding and problem-solving skills in physics (Rianti et al., 2024).

Technology-enhanced learning environments also promote interactive and student-centered learning. Augmented reality applications enable teachers and students to interact with digital objects during learning, thereby improving engagement and collaboration (Nurhasanah et al., 2021). Similarly, virtual laboratories enable students to conduct experiments in digital environments, which helps them explore scientific concepts more independently (Syukriah et al., 2025).

Additionally, immersive technologies such as virtual reality support experiential learning by allowing students to observe and interact with simulated environments (Al Amri et al., 2020). This approach enhances students' motivation and encourages deeper exploration of physics concepts.

Another important finding is that digital technology was rarely implemented as a stand-alone instructional tool. Instead, most of the reviewed studies integrated technology with pedagogical approaches such as problem-based learning, flipped classroom learning, inquiry-based learning, and scaffolding. This pattern indicates that technology serves as a medium for facilitating active learning rather than replacing the learning process itself. Bond et al. (2021) also emphasized that digital technology contributes more effectively to learning when it is integrated into student-centered instructional strategies. Therefore, successful technology integration depends not only on the availability of digital tools but also on how teachers design meaningful learning experiences.

Challenges and Opportunities in Technology-Enhanced Physics Education for Sustainable Development

Although digital technologies provide many benefits for physics education, several challenges remain in their implementation. One major challenge is the availability of technological infrastructure, including access to digital devices, internet connectivity, and appropriate learning platforms. Limited technological resources can hinder the effective implementation of technology-enhanced learning environments and reduce the potential benefits of digital learning innovations (Al Amri et al., 2020; Nurhasanah et al., 2021). In many educational contexts, unequal access to technological infrastructure may limit students' opportunities to participate in digital learning activities.

Another challenge relates to teachers' readiness to integrate digital technology into their teaching practices. Teachers require adequate training, pedagogical knowledge, and digital literacy to implement technology-enhanced learning strategies effectively in the classroom. Previous studies have shown that the successful integration of technology in education depends not only on the availability of tools but also on teachers' competence in designing meaningful learning experiences using digital technology (Johnson-Glenberg & Megowan-Romanowicz, 2017; Karim et al., 2025). Without sufficient professional development and institutional support, the integration of digital technology may not achieve its full educational potential.

Despite these challenges, the integration of digital technology in physics education offers significant opportunities to support sustainable education. Technology-enhanced learning environments can improve students' digital literacy, promote critical thinking and problem-solving skills, and encourage collaborative learning practices (Yunzal & Casinillo, 2020; Syukriah et al., 2025). These competencies are essential for preparing students to address global sustainability challenges and to develop scientific literacy in the context of modern society.

Moreover, technology-based learning environments enable flexible, accessible education, allowing students to learn anytime, anywhere through digital platforms and interactive learning resources. This flexibility supports more inclusive and learner-centered education, aligning with the principles of Education for Sustainable Development (ESD), which emphasize innovation, accessibility, and lifelong learning opportunities (Snyder, 2019; Alhusni et al., 2025). Therefore, the integration of digital technology in physics education has strong potential to contribute to sustainable education by creating more engaging, interactive, and accessible learning environments.

Although the reviewed studies consistently reported positive impacts of digital technology, they also identified several common challenges. Most studies highlighted the importance of adequate technological infrastructure and teachers' digital competence for effective implementation. UNESCO (2023) emphasized that improving teachers' digital literacy is essential to maximizing the educational benefits of technology, while OECD (2021) noted that access to digital resources remains unequal across educational contexts. These findings indicate that successful technology integration requires not only appropriate digital tools but also continuous professional development and institutional support.

Overall, the reviewed studies demonstrate that digital technology has become an integral part of physics education, not only as a tool for delivering learning materials but also as a means of supporting active and meaningful learning. The findings show that different technologies provide different educational benefits depending on the characteristics of the physics concepts and the pedagogical approaches used. Simulation-based technologies mainly support conceptual understanding and scientific inquiry, whereas augmented reality and virtual reality strengthen visualization and student engagement. When integrated with learner-centered approaches such as problem-based and inquiry-based learning, these technologies also contribute to the development of problem-solving, digital, and scientific literacy, which are important competencies for Education for Sustainable Development.

CONCLUSION

Fundamental Findings: This literature review highlights that various forms of digital technology, such as simulations, virtual laboratories, augmented reality (AR), virtual reality (VR), and digital learning resources, play an important role in enhancing physics learning. The reviewed studies indicate that these technologies support the visualization of abstract physics concepts, increase students' engagement and motivation, and improve conceptual understanding and problem-solving skills. In addition, integrating digital technology with pedagogical approaches such as problem-based learning, flipped classroom learning, and scaffolding strategies fosters more interactive, student-centered learning environments that support the principles of sustainable education. **Implications:** These findings imply that integrating digital technologies into physics education can help develop essential competencies such as digital literacy, critical thinking, and scientific problem-solving, which are important for preparing students to address sustainability challenges. Therefore, educators and educational institutions are encouraged to integrate technology-enhanced learning environments to create more engaging and accessible physics learning experiences. **Limitations:** However, this study is limited by the number of reviewed articles and the diversity of research contexts and technologies used in the selected studies, which may affect the generalizability of the findings. **Future Research:** Future research should explore a wider range of digital technologies and educational contexts and investigate the long-term impact of technology-enhanced physics education on students' scientific literacy, sustainability awareness, and higher-order thinking skills.

AUTHOR CONTRIBUTIONS

Ike Nurdela Anggraini contributed to the conceptual framework, research design, and validation process; **Rahmatta Thoriq Lintangesukmanjaya & Dwikoranto** was involved in methodology development, data analysis, sourcing references, and drafting the manuscript; **Salma Hasna Hamiydah & Lindsay Natalia Bergsma** was involved in methodology development and drafting the manuscript. **Neisya Azaria Adinda Putri** handled data management. All listed authors have reviewed and approved the final version of this submission.

CONFLICT OF INTEREST STATEMENT

The authors confirm that there are no conflicts of interest, either financial or personal, that may have influenced the content or outcome of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors acknowledge the use of digital tools, including AI-based technology, as support during the research and writing of this article. Specifically, Grammerly is a writing aid that offers various advantages in improving English language quality. All written work produced with digital assistance has been critically evaluated and revised to ensure compliance with academic and ethical standards. Final responsibility for the manuscript rests solely with the authors.

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