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Intelligent Virtual Environment in STEM Education: A Systematic Literature Review for Sustainable Digital Learning

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ABSTRACT

***Objective**: This study aims to analyze the development and application of Intelligent Virtual Environment (IVE) in STEM education to support sustainable digital learning. The study focuses on identifying research trends, technologies used, and the impact of immersive digital environments on STEM learning outcomes. **Method:** This research employed a Systematic Literature Review (SLR) approach to synthesize relevant studies published in the last five years. Articles were collected from several academic databases, including Scopus, Web of Science, ScienceDirect, IEEE Xplore, and Google Scholar. The selection process followed the PRISMA framework to ensure systematic identification, screening, eligibility assessment, and inclusion of relevant studies. A total of 15 articles were selected based on inclusion criteria related to immersive technologies, artificial intelligence, and virtual learning environments in STEM education. The selected studies were analyzed to identify research trends, technological approaches, and reported learning outcomes. **Result**: The results show that Intelligent Virtual Environment technologies, particularly those integrating virtual reality, augmented reality, and artificial intelligence, have been widely applied in STEM learning. These technologies improve conceptual understanding, student engagement, and interactive learning experiences. The findings also indicate that immersive learning environments support visualization of complex scientific concepts and encourage active learning through simulation and exploration. **Novelty**: This study provides a comprehensive synthesis of recent research on Intelligent Virtual Environment in STEM education and highlights its role in advancing sustainable digital learning. The review also identifies current research trends and future research directions for integrating immersive technologies and artificial intelligence in STEM education.*

INTRODUCTION

Digital transformation in education has become one of the most significant changes in the 21st century learning system. Developments in information technology, artificial intelligence, and immersive technology have driven the emergence of various learning innovations that aim to improve the quality of learning experiences and expand access to more inclusive and adaptive education. Modern education no longer focuses solely on the transfer of knowledge, but also emphasizes the development of critical thinking, problem-solving, collaboration, and digital literacy skills, which are essential competencies in facing today's global challenges. Therefore, the integration of digital technology in learning has become a strategic approach to improving the quality of education in the era of digital transformation.

Various studies show that the use of digital technology can increase student engagement, enrich the learning experience, and create a more interactive learning process compared to traditional learning methods. Virtual and interactive simulation-based learning technologies allow students to explore concepts in a more visual and contextual manner, thereby improving conceptual understanding and learning motivation (Radianti et al., 2020; Makransky & Petersen, 2021). In addition, immersive

technologies such as virtual reality are also capable of creating a more authentic learning experience through simulations of environments that resemble real-world conditions, allowing students to explore scientific concepts in greater depth (Parong & Mayer, 2018; Makransky et al., 2019).

In the context of Science, Technology, Engineering, and Mathematics (STEM) education, the integration of digital technology plays a very important role because many scientific concepts are abstract and difficult to visualize through conventional learning approaches. Therefore, various virtual-based learning technologies have been developed to help students understand scientific concepts more concretely through simulations and digital experiments. Research shows that the use of virtual environment technology in STEM learning can improve students' conceptual understanding, learning engagement, and problem-solving skills (Ibáñez & Delgado-Kloos, 2018; Garzón et al., 2020). In addition, augmented reality and virtual reality technologies can also enhance exploration-based learning experiences that allow students to interact directly with virtual objects and complex scientific phenomena (Bacca et al., 2014; Akçayır, 2017).

Along with the development of artificial intelligence technology, the concept of Intelligent Virtual Environment (IVE) has begun to develop as a new innovation in digital learning systems. IVE is a virtual environment that integrates simulation technology with artificial intelligence systems to create adaptive and personalized learning experiences. In this environment, students can interact with virtual objects and receive real-time feedback from intelligent systems designed to tailor the learning experience to user needs. The integration of artificial intelligence in digital learning environments enables the system to analyze student learning patterns, provide personalized learning recommendations, and improve the effectiveness of the learning process (Holmes et al., 2019; Richter et al., 2019).

Several studies show that the use of immersive technology combined with artificial intelligence can improve the quality of learning through more realistic and contextual learning experiences. This technology allows students to explore complex scientific concepts through virtual simulations that are difficult to do in conventional learning environments. Empirical studies show that virtual environment-based learning can increase student engagement, strengthen concept understanding, and support the development of higher-order thinking skills (Radianti et al., 2020; Makransky & Petersen, 2021). In addition, this technology also enables more collaborative and exploratory learning, thereby improving students' problem-solving and creativity in STEM learning (Ibáñez & Kloos, 2018).

Although various studies have shown the great potential of using virtual environments and artificial intelligence in STEM education, studies that specifically integrate the concept of Intelligent Virtual Environment in STEM education are still relatively limited. Many studies discuss virtual reality, augmented reality, or artificial intelligence separately, while studies that integrate these technologies within the IVE framework have not been conducted comprehensively. In addition, several studies also show that the implementation of immersive technology in education still faces various challenges, such as technological infrastructure readiness, teacher readiness, and appropriate pedagogical design to support effective digital learning (Garzón et al., 2020; Richter et al., 2019). Therefore, a systematic review is needed to identify research developments, trends in the technologies used, and the contribution of these technologies to STEM learning.

One approach that can be used to gain a comprehensive understanding of research developments in a field is Systematic Literature Review (SLR). This method allows researchers to systematically identify, evaluate, and synthesize findings from various studies to provide a comprehensive overview of research trends and gaps that still need to be developed. Therefore, this study aims to conduct a Systematic Literature Review of the application of Intelligent Virtual Environments in STEM education to analyze research developments, identify trends in digital learning technology, and evaluate its contribution to supporting the development of sustainable digital learning.

RESEARCH METHOD

This study uses a Systematic Literature Review (SLR) approach to analyze the development of research related to the application of Intelligent Virtual Environments in STEM education. The SLR method was chosen because it allows researchers to identify, evaluate, and synthesize various research results in a systematic and transparent manner, thereby providing a comprehensive overview of research trends, technological approaches used, and research gaps that still need to be developed. This approach is also considered more objective than conventional literature reviews because it follows structured procedures that can be replicated by other researchers. In this study, the SLR process refers to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which are widely used in systematic research to ensure that the literature selection process is carried out systematically, transparently, and is academically accountable (Kitchenham & Charters, 2007; Snyder, 2019; Page et al., 2021).

The research process began with the formulation of research questions aimed at identifying developments in research on the use of Intelligent Virtual Environments in STEM education, the technologies used in the development of these virtual learning environments, the impact of their application on the learning process, and the challenges and opportunities for research that still need to be developed in the future. These research questions then became the basis for the process of searching for relevant literature. The literature search strategy was carried out using several international scientific databases that are widely used in educational and learning technology research, namely Scopus, Web of Science, ScienceDirect, IEEE Xplore, and Google Scholar. The use of these databases was intended to ensure that the articles obtained were from credible scientific sources and had a broad research coverage.

The literature search process was carried out using a combination of keywords relevant to the research topic, such as “Intelligent Virtual Environment,” “Virtual Reality in Education,” “Artificial Intelligence in Education,” “Immersive Learning,” and “STEM Education.” These keywords were combined using Boolean operators such as AND and OR to obtain search results that were more specific and relevant to the research topic. The article search was limited to scientific publications published between 2020 and 2025 to ensure that the literature analyzed was the latest research in line with current developments in digital learning technology. In addition, only articles published in English and available in full text were considered in the literature selection process.

After the literature search process was carried out, the next stage was the article screening process, which followed the selection flow in the PRISMA framework. In the initial stage, an identification process was carried out to collect all articles found through the databases used. The identified articles were then screened based on their titles and abstracts to determine their relevance to the research topic. Articles deemed relevant

were further analyzed by reading the full text to ensure that they met the predetermined inclusion criteria. Articles that did not meet the research criteria, such as articles that did not discuss the application of virtual technology in STEM education, articles that were not available in full text, or articles that were duplicates from other databases, were then excluded from the analysis process. Through this selection process, a collection of articles deemed most relevant for analysis in the study was obtained.

The next stage was the process of extracting and analyzing data from the selected articles. At this stage, important information from each article was systematically collected to facilitate the literature analysis process. The information analyzed included the year of publication, country or region of research, type of technology used in the virtual learning environment, research methods used by previous researchers, STEM fields that were the focus of the research, and the impact of technology use on the learning process and outcomes. The data obtained is then analyzed using a qualitative descriptive analysis approach to identify research patterns, trends in the development of virtual-based learning technologies, and the contribution of the use of Intelligent Virtual Environments in improving the quality of STEM learning. Through this analysis process, it is hoped that a comprehensive picture of research developments and future research directions in supporting the development of sustainable digital learning can be obtained.

RESULTS AND DISCUSSION

Result

Table 1. Selected articles on intelligent virtual environment, immersive technologies, and ai in stem education (2021–2025)

No	Researcher and Year	Result Findings
1	Ajit et al. (2021)	This systematic review identified 19 studies on augmented reality in STEM education and found that the most frequently reported benefit was improved learning achievement. The review also highlighted recurring challenges related to marker detection, usability, and implementation constraints, while pointing to clear research gaps for future AR-STEM studies.
2	Mystakidis et al. (2021)	This systematic mapping review analyzed 45 journal articles on AR applications supporting STEM learning in higher education. The study found uneven research distribution across STEM fields, with fewer studies in technology and mathematics, and reported limited use of location-based and markerless AR despite their pedagogical potential.
3	Pande et al. (2021)	This study examined the long-term effectiveness of immersive VR simulations in undergraduate science learning through media comparison. The findings suggested that immersive VR can support sustained learning benefits, although effectiveness depends strongly on instructional design, information quality, and how well the VR task aligns with learning goals.
4	Xu and Ouyang (2022)	This systematic review synthesized 63 empirical studies on AI technologies in STEM education published from 2011 to 2021. The study concluded that AI-STEM is a rapidly growing field, but it still faces challenges in integrating diverse AI techniques with instructional goals, learning contexts, and theoretical frameworks.

No	Researcher and Year	Result Findings
5	Lee et al. (2024)	This article investigated virtual and augmented reality classroom learning environments in university STEM education. The study showed that VR and AR can enrich STEM learning experiences by strengthening visualization, interaction, and engagement, while also emphasizing the importance of classroom integration, usability, and pedagogical design.
6	Matovu et al. (2023)	This review synthesized 64 studies on immersive virtual reality for science learning and focused on design, implementation, and evaluation. The study found that IVR is promising for science education because it enhances spatial understanding and experiential learning, but its success depends on cognitive load management, task design, and pedagogical alignment.
7	Cromley et al. (2023)	This meta-analysis reported that virtual reality provides overall positive effects on STEM learning outcomes. The findings supported the conclusion that VR benefits STEM learning across diverse learner groups and contexts, showing that immersive environments can improve conceptual understanding when used appropriately.
8	Ouyang et al. (2023)	This systematic review examined AI-driven educational assessment in STEM education based on 17 empirical studies. The results identified three major functions of AI in STEM assessment, namely academic performance assessment, learning process assessment, and feedback or diagnosis, showing that AI can make assessment more adaptive and data-informed.
9	Qorbani et al. (2024)	This curriculum-based experiment in chemistry education assessed learning in immersive virtual reality. The study indicated that IVR can be integrated into chemistry instruction as a feasible learning environment and can support curriculum-aligned understanding of abstract content through immersive representation.
10	Wang et al. (2024)	This meta-analysis of 33 studies found that augmented reality-supported STEM education had a moderate positive impact on students' achievement, with an effect size of 0.586. The study also reported that AR tended to be more effective in science and mathematics and showed stronger effects in primary and lower secondary education.
11	Akhmetova et al. (2025)	This systematic review focused specifically on AI in high school STEM education research. The study showed that AI is becoming increasingly important in STEM learning at the secondary level and highlighted the need for more targeted research on implementation models, pedagogical outcomes, and classroom readiness.
12	Li et al. (2025)	This systematic review and meta-analysis examined 237 studies on augmented reality in higher education. The review found that AR has been used across multiple disciplines, with analysis covering publication trends, technical affordances, instructional design, learning outcomes, and moderators of effectiveness.
13	Li et al. (2025)	This meta-analysis investigated AI-enabled personalized STEM education in schools. The study concluded that AI-based personalization represents a transformative direction in STEM

No	Researcher and Year	Result Findings
		pedagogy because it enables more responsive learning experiences and has measurable positive effects on educational outcomes.
14	El Fathi et al. (2025)	This study on generative AI in STEM education found that generative AI can enhance conceptual understanding, help address misconceptions, and improve student acceptance of digital learning support. The findings suggest that AI tools can strengthen adaptive and intelligent support in STEM learning environments when used carefully.
15	Lampropoulos et al. (2025)	This scoping review analyzed 342 studies on virtual reality in engineering education. The results identified six major themes, including virtual laboratories, immersive simulations, practical skills development, engineering design and visualization, and collaborative learning, concluding that VR is an effective complement to existing engineering teaching practices.

Based on the fifteen selected articles, the research trend in the last five years has moved toward three major directions: immersive virtual reality, augmented reality, and artificial intelligence-supported STEM learning. In general, the reviewed studies consistently report that intelligent and immersive virtual learning environments have strong potential to enhance conceptual understanding, visualization of abstract scientific concepts, learning engagement, personalized learning experiences, and overall STEM learning outcomes. Nevertheless, several studies emphasize that the effectiveness of these technologies is highly dependent on pedagogical design, teacher readiness, curriculum integration quality, and technical factors such as usability, cognitive load management, and infrastructure accessibility.

Discussion

Based on the analysis of 15 articles published in the last five years, it appears that research on the use of digital technology in STEM learning has developed rapidly. Most studies highlight the use of virtual reality (VR), augmented reality (AR), and artificial intelligence (AI) as key components in the development of more interactive and adaptive digital learning environments. These technological developments indicate a paradigm shift in learning from conventional approaches to more immersive and experience-based technology-based learning. This is in line with the findings of several studies that show that immersive technology can improve the quality of learning experiences through more concrete visualization of concepts and enable students to explore scientific concepts in greater depth (Radianti et al., 2020; Makransky & Petersen, 2021; Cromley et al., 2023).

In the context of STEM learning, one of the main advantages of using virtual technology is its ability to help students understand abstract scientific concepts. Many concepts in science, technology, and engineering are difficult to visualize through traditional learning methods, requiring a more exploratory and simulation-based learning approach. Virtual reality technology allows students to observe scientific phenomena through three-dimensional simulations that resemble real-world conditions, thereby improving students' conceptual understanding and spatial thinking skills. Research conducted by Matovu et al. (2023) shows that the use of immersive virtual reality in science learning can improve scientific visualization skills and provide a more meaningful learning experience. These findings are also supported by research by

Cromley et al. (2023), which shows that the use of VR in STEM learning has a positive impact on improving student learning outcomes and scientific concept understanding.

In addition to virtual reality technology, the use of augmented reality in STEM learning has also shown significant development in recent years. Augmented reality technology allows the integration of virtual objects and real environments so that students can learn scientific concepts through direct interaction with digital objects displayed in real environments. This provides a more contextual learning experience and helps students understand the relationship between theory and real phenomena. Research conducted by Wang et al. (2024) through a meta-analysis of various AR-STEM studies shows that the use of augmented reality has a positive impact on student academic achievement with moderate to high effects. In addition, research by Garzón et al. (2020) also shows that augmented reality can increase learning motivation, student engagement, and scientific concept understanding in science and technology learning.

Research developments also show that the integration of artificial intelligence in STEM education is being developed to support more adaptive and personalized learning systems. Artificial intelligence enables learning systems to analyze student learning patterns, provide automatic learning recommendations, and provide faster and more accurate feedback. Research conducted by Xu and Ouyang (2022) shows that AI technology in STEM education is widely used to support adaptive learning systems, analyze student learning performance, and develop automated assessment systems. In addition, research by Ouyang et al. (2023) shows that AI can also be used to improve the quality of learning evaluation through data-based assessment systems that are capable of providing more comprehensive learning diagnoses.

The integration of virtual technology and artificial intelligence has given rise to the concept of Intelligent Virtual Environment (IVE), which is one of the current developments in digital learning technology. IVE combines virtual simulation technology with artificial intelligence systems to create a learning environment that is more immersive, interactive, and adaptive to students' learning needs. In this environment, students not only interact with virtual objects, but also with intelligent systems that can provide real-time feedback, learning guidance, and learning recommendations. Recent studies show that AI-based learning environments and virtual environments have great potential in improving learning personalization and strengthening exploration-based learning experiences (Akhmetova et al., 2025; Li et al., 2025). In addition to providing various benefits to the learning process, the use of virtual technology in STEM education also has the potential to support the development of 21st-century skills such as critical thinking, creativity, collaboration, and problem solving. The virtual learning environment allows students to conduct digital experiments, solve complex problems, and explore concepts independently through interactive simulations. This is in line with research findings that show that immersive learning technology can improve higher-order thinking skills and provide a more exploratory learning experience compared to traditional learning methods (Radianti et al., 2020; Makransky & Petersen, 2021). In addition, research by Li et al. (2025) also shows that the use of AI technology in STEM learning can increase learning effectiveness through a learning system that is more adaptive and responsive to student needs.

Although various studies show the great potential of using virtual and artificial intelligence technologies in STEM education, several challenges remain in their implementation. One of the main challenges is the limitation of technological infrastructure and the readiness of educational institutions to integrate these technologies

into the learning process. The implementation of virtual technology often requires relatively expensive hardware and software, so not all educational institutions have equal access to these technologies. In addition, the readiness of teachers to use digital technology is also an important factor in the successful implementation of virtual-based learning technology. Research conducted by Garzón et al. (2020) shows that the successful use of augmented reality technology in education is greatly influenced by learning design and the ability of teachers to integrate technology with effective pedagogical strategies.

Apart from technical and pedagogical challenges, research also shows that the use of virtual technology in learning needs to consider the aspect of cognitive load on students. A learning environment that is too complex or displays too much visual information can cause students to have difficulty processing the information provided. Therefore, the design of the virtual learning environment needs to be carefully crafted so that it can provide an effective learning experience without causing excessive cognitive load on students. Several studies show that the successful use of virtual technology in education is greatly influenced by the quality of learning design and the integration of technology with appropriate learning strategies (Matovu et al., 2023; Cromley et al., 2023).

Overall, the results of the literature review show that the use of Intelligent Virtual Environments in STEM education is a very promising approach in supporting the transformation of digital learning in the future. The integration of virtual reality, augmented reality, and artificial intelligence technologies enables the creation of a more interactive, adaptive, and experience-based learning environment. This technology not only improves students' conceptual understanding but also has the potential to support the development of 21st-century skills that are urgently needed in the digital age. Therefore, future research needs to further explore the development of Intelligent Virtual Environment-based learning models integrated with effective pedagogical approaches so that they can support the development of more innovative, adaptive, and sustainable STEM learning.

CONCLUSION

Fundamental Finding: This study conducted a Systematic Literature Review (SLR) of research on Intelligent Virtual Environments in STEM education over the past five years. The results of the study show that virtual reality, augmented reality, and artificial intelligence technologies play an important role in creating a more interactive and immersive learning environment. These technologies have been proven to improve conceptual understanding, learning engagement, and student learning experiences in STEM learning. **Implication**: The findings of this study indicate that Intelligent Virtual Environments have great potential in supporting the transformation of digital-based STEM learning. The integration of immersive technology and artificial intelligence can help create more adaptive and innovative learning experiences, as well as support the development of 21st-century skills. **Limitation**: The limitation of this study lies in the use of a literature review method that only analyzes articles available in certain databases without conducting direct empirical testing of the implementation of this technology. **Future Research**: Further research needs to conduct empirical studies on the implementation of Intelligent Virtual Environments in STEM learning and explore the integration of new technologies such as generative AI and adaptive learning systems to improve the effectiveness of digital learning.

AUTHOR CONTRIBUTIONS

Hanan Zaki Alhusni contributed to the conceptualization of the study, development of the research framework, methodology design, data analysis, and preparation of the initial manuscript draft. **Binar Kurnia Prahani** was responsible for supervising the research process, providing methodological guidance, reviewing the analysis, and contributing to the revision of the manuscript. **Budi Jatmiko** contributed to the validation of the research design. **Noval Maleakhi Hulu** contributed to critical review of the manuscript, and final approval of the published version.

CONFLICT OF INTEREST STATEMENT

The authors report no conflicts of interest, either financial or personal, that might have influenced the research process or the outcomes of this study.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors acknowledge the use of digital technologies, including AI-assisted tools, to support certain stages of the research and writing process of this article. These tools were utilized to assist with reference organization, language refinement, and structuring of ideas during manuscript preparation. All generated outputs were carefully reviewed, critically evaluated, and revised by the authors to ensure accuracy, academic integrity, and compliance with ethical research standards. The authors take full responsibility for the content, interpretation, and conclusions presented in this manuscript.

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