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INTEGRATION OF DIGITAL TECHNOLOGY IN SCIENCE LEARNING TO ENHANCE STUDENT MOTIVATION, CRITICAL THINKING SKILLS, AND LEARNING OUTCOMES

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Abstract

The advancement of digital technology has led to changes in science learning by using various innovations such as Artificial Intelligence (AI), Virtual Reality (VR), Internet of Things (IoT), flipped classroom methods, gamification, and digital game-based learning. This article aims to examine the role of integrating digital technology in improving students' learning motivation, critical thinking skills, and learning outcomes in science education. This study uses a library research method with a descriptive qualitative approach by analyzing 15 scientific articles published in reputable national and international journals. Data analysis involves identifying, comparing, and combining findings from each study according to the research focus. The study shows that using digital technology in science learning can increase students' learning motivation, their active participation, critical thinking skills, investigative abilities, and cognitive learning outcomes. In addition, digital technology supports more interactive, collaborative, adaptive, and student-centered learning, which is able to meet the demands of 21st-century competencies. Even so, the success of implementing digital technology depends on the teachers' abilities, students' readiness, and the availability of supporting facilities and infrastructure. Therefore, the integration of digital technology should be designed in a systematic way to improve the quality of science learning continuously.

INTRODUCTION

The development of digital technology has brought significant changes to the education world, especially in the teaching of science. Different innovations such as

Artificial Intelligence (AI), Virtual Reality (VR), Internet of Things (IoT), flipped classroom, gamification, and digital game-based learning are now being used to create more interactive, collaborative, and student-centered learning experiences. The use of digital technology is expected to improve the quality of learning and help students develop 21st-century skills such as critical thinking, creativity, collaboration, and digital literacy (Ayeni et al., 2024; Wahyudin et al., 2026).

Even so, science learning still faces several challenges, such as low student motivation, lack of active participation from learners, and the widespread use of traditional teaching methods that lead to students being passive. This situation affects students' ability to think critically and their learning outcomes. Therefore, there is a need for technological-based learning innovations that can improve the effectiveness of the learning process and create more meaningful learning experiences (Arifin et al., 2025; Godsk & Møller, 2025).

Studies show that using digital technology in science learning has many good effects. Digital game-based learning and gamification have been shown to boost students' motivation, engagement, and understanding of concepts (Al-Muqbali et al., 2026; Coelho et al., 2025; Ortiz-Rojas et al., 2025). In addition, the use of flipped classroom, AI, VR, and IoT helps improve critical thinking skills, learning outcomes, technological abilities, and provides a more personal and interactive learning experience (Zhaiynbayeva et al., 2026; Ay & Dağhan, 2023; Syafruddin et al., 2023; Chávez-Arizala & Soria-Quijaite, 2026).

However, most of the research still focuses on one type of technology or a specific learning model. Even though it may seem like it, the development of educational technology shows that various digital innovations can work together to improve the quality of science learning. Therefore, it is necessary to conduct a study that integrates various research findings in order to provide a more comprehensive understanding of the effectiveness of digital technology in improving students' learning motivation, critical thinking skills, and learning outcomes.

Based on that explanation, the article aims to examine and summarize the results of various studies on the integration of digital technology in science learning using library research methods with a descriptive qualitative approach. The study results are expected to provide information on the effectiveness of various digital learning innovations and serve as a reference for educators in developing innovative, adaptable, and competency-oriented science teaching that meets the demands of the 21st century.

LITERATURE REVIEW

Digital Technology in Science Education

Digital technology has become one of the main drivers of educational transformation, particularly in science education. The rapid advancement of digital technologies has shifted learning from traditional teacher-centered instruction to student-centered learning that emphasizes interaction, collaboration, and active participation. Technologies such as Artificial Intelligence (AI), Virtual Reality (VR), Internet of Things (IoT), gamification, digital game-based learning, and flipped classroom models provide innovative learning experiences by facilitating virtual experiments, scientific simulations, personalized learning, and collaborative activities. These technologies help students visualize abstract scientific concepts, improve conceptual understanding, and develop scientific inquiry skills. Consequently, the integration of digital technology not

only enhances students' academic achievement but also prepares them with digital competencies required in the twenty-first century (Ayeni et al., 2024; Braun & Huwer, 2022; Godsk & Møller, 2025; Wahyudin et al., 2026).

Furthermore, digital technology enables teachers to design adaptive learning environments that accommodate students' different learning needs and abilities. AI-powered systems provide personalized learning pathways, while virtual laboratories and multimedia resources encourage students to engage actively in scientific investigations. Therefore, successful integration of digital technology depends not only on technological availability but also on teachers' pedagogical competence and effective instructional design that aligns technology with learning objectives (Ayeni et al., 2024; Godsk & Møller, 2025).

Student Learning Motivation in Science Education

Learning motivation is considered one of the most influential factors affecting students' participation and achievement in science learning. Motivation encourages students to actively engage in classroom activities, maintain persistence when solving scientific problems, and develop curiosity toward scientific phenomena. In science education, motivated students are more likely to participate in experiments, collaborate with peers, and construct scientific knowledge through inquiry-based learning. Therefore, maintaining high learning motivation is essential for improving both cognitive achievement and scientific competence.

The integration of digital technology has been widely reported to strengthen students' motivation by creating engaging, interactive, and meaningful learning experiences. Gamification, digital game-based learning, AI-supported learning, and multimedia applications provide immediate feedback, personalized learning experiences, and interactive challenges that encourage students to become more actively involved in the learning process. As students experience greater autonomy and enjoyment during learning, their intrinsic motivation increases, resulting in improved academic performance and sustained engagement in science education (Coelho et al., 2025; Ortiz-Rojas et al., 2025; Al-Muqbali et al., 2026).

Critical Thinking Skills in Science Learning

Critical thinking is recognized as one of the essential competencies in twenty-first-century education, particularly in science learning, where students are expected to analyze evidence, evaluate information, formulate hypotheses, and solve real-world problems using scientific reasoning. Science education requires students not only to memorize concepts but also to develop analytical and reflective thinking skills through observation, experimentation, and scientific inquiry. Therefore, instructional approaches that encourage active investigation play an important role in developing students' critical thinking abilities.

Previous studies have demonstrated that digital technology contributes significantly to the development of critical thinking skills. Inquiry-based learning, flipped classroom, Virtual Reality (VR), and IoT-supported learning environments encourage students to investigate scientific phenomena independently, collaborate with peers, interpret scientific evidence, and make informed decisions. These technology-supported learning approaches shift students from passive recipients of information to active participants in knowledge construction, thereby strengthening higher-order

thinking skills and improving science learning outcomes (Arifin et al., 2025; Ay & Dağhan, 2023; Syafruddin et al., 2023).

The Relationship Between Digital Technology and Student Motivation

The relationship between digital technology and student learning motivation has become an important topic in contemporary educational research. Digital technology creates learning environments that are more interactive, flexible, and student-centered, allowing learners to actively participate in scientific exploration. Interactive multimedia, virtual simulations, educational games, and adaptive learning systems increase students' curiosity and engagement by providing meaningful learning experiences that are difficult to achieve through conventional teaching methods.

Several empirical studies have consistently reported that Artificial Intelligence (AI), gamification, digital game-based learning, and Virtual Reality (VR) positively influence students' motivation by enhancing engagement, providing immediate feedback, and supporting personalized learning experiences. Higher levels of motivation encourage students to participate more actively in scientific inquiry, improve their confidence in solving scientific problems, and ultimately contribute to better learning outcomes. These findings suggest that digital technology functions not only as an instructional tool but also as an important motivational factor in science education (Ayeni et al., 2024; Coelho et al., 2025; Ortiz-Rojas et al., 2025; Al-Muqbali et al., 2026).

Conceptual Framework of the Study

This study is based on the assumption that the integration of digital technology contributes to improving science learning by creating interactive learning environments that increase student engagement and motivation. Increased motivation encourages students to participate actively in scientific inquiry, develop critical thinking skills, and achieve better learning outcomes. Therefore, digital technology is expected to influence science learning both directly through innovative instructional media and indirectly through increased learning motivation and active student participation.

Based on the reviewed literature, this study synthesizes previous findings to examine how various digital technologies contribute to science learning and student motivation. The conceptual framework proposes that digital technology serves as the primary instructional factor that enhances student engagement, strengthens learning motivation, supports critical thinking, and ultimately improves science learning outcomes. This framework provides the theoretical foundation for analyzing the findings presented in the Results and Discussion section.

RESEARCH METHODS

This study employed a library research method using a descriptive qualitative approach. The study aimed to synthesize findings from previous scientific publications concerning the integration of digital technology in science education. Data were collected from fifteen peer-reviewed journal articles published between 2022 and 2026. The articles were selected based on three criteria: relevance to science education, discussion of digital technology integration, and publication in reputable national or international journals. The data collection process involved identifying, selecting, reviewing, and classifying the selected articles according to the research objectives. Subsequently, qualitative content

analysis was conducted by comparing, interpreting, and synthesizing the findings from each study. Finally, conclusions were drawn to identify the overall effectiveness of digital technology in improving learning motivation, critical thinking skills, and learning outcomes in science education.

RESULTS AND DISCUSSION

Based on the analysis of fifteen scientific articles published between 2022 and 2026, this study found that the integration of digital technology has consistently contributed to improving the quality of science learning. The reviewed studies employed various research methods, including systematic literature reviews, meta-analyses, experimental studies, mixed-methods research, and implementation studies. The digital technologies discussed include Artificial Intelligence (AI), Virtual Reality (VR), Internet of Things (IoT), gamification, digital game-based learning, flipped classroom, inquiry-based learning, computational literacy, data literacy, and the Science–Technology–Society (STS) approach. Despite differences in educational contexts and research designs, the findings consistently demonstrate that digital technology positively influences students' learning motivation, critical thinking skills, scientific literacy, engagement, and academic achievement (Ayeni et al., 2024; Arifin et al., 2025; Wahyudin et al., 2026). A summary of the reviewed studies is presented in Table 1.

Table 1. Summary of Research Results on the Integration of Digital Technology in Science Learning (2022–2026)

No	Researcher & Year	Method	Research Focus	Digital Technology	Key Findings
1	Antonio & Prudente (2022)	Metaanalysis	Metacognitive teaching	Metacognitive Teaching	Improves students' science learning achievement and higher-order thinking skills.
2	Braun & Huwer (2022)	Systematic Review	Computational literacy in science education	Computational Literacy	Computational literacy improves students' scientific thinking and problem-solving skills.
3	Acut & Antonio (2023)	Meta-analysis	Science learning outcomes	Science–Technology–Society (STS)	The STS approach improves science learning outcomes and scientific literacy.
4	Ay & Dağhan (2023)	Experimental Study	Critical thinking development	Flipped Classroom	Improves critical thinking skills, learning interaction, and student activeness.
5	Syafruddin et al. (2023)	Meta-analysis	Critical thinking in science learning	IoT-Based Flipped Classroom	Significantly improves students' critical thinking skills.
6	Ayeni et al. (2024)	Literature Review	Artificial intelligence in	Artificial Intelligence (AI)	AI supports personalized

			education		learning and increases students' learning motivation.
7	Friedrich et al. (2024)	Systematic Review	Data literacy in science education	Data Literacy	Improves students' data analysis skills and scientific literacy.
8	Arifin et al. (2025)	Systematic Review & Meta-analysis	Inquiry-based science learning	Inquiry-Based Learning	Significantly improves students' critical thinking skills.
9	Coelho et al. (2025)	Randomized Controlled Trial	Motivation through educational games	Gamification	Increases motivation, positive emotions, and learning outcomes.
10	Godsk & Møller (2025)	Literature Study	Technology-supported higher education	Educational Technology	Digital technology increases student engagement in learning.
11	Ortiz-Rojas et al. (2025)	Mixed Methods	Gamification in STEM education	Gamification	Improves learning motivation and conceptual understanding.
12	Al-Muqbali et al. (2026)	Experimental Study	Digital game-based science learning	Digital Game-Based Learning	Increases motivation and understanding of science concepts.
13	Chávez-Arizala & Soria-Quijaite (2026)	SEM Analysis	Digital competence and scientific skills	Technological Skills	Digital skills improve students' investigative capabilities.
14	Wahyudin et al. (2026)	Experimental Study	Virtual reality in science learning	Virtual Reality (VR)	VR improves students' cognitive learning outcomes.
15	Zhaiynbayeva et al. (2026)	Model Implementation	Flipped classroom implementation	Flipped Classroom	Improves professional competence and active learning.

The synthesis of the reviewed studies indicates that digital technology has become an important element in transforming science education from teacher-centered instruction into more interactive and learner-centered learning. Technologies such as Artificial Intelligence (AI), Virtual Reality (VR), gamification, digital game-based learning, and flipped classroom provide students with opportunities to actively construct knowledge through exploration, collaboration, and scientific investigation. As a result, students become more engaged in classroom activities while developing deeper conceptual understanding and stronger scientific reasoning skills (Ayeni et al., 2024; Braun & Huwer, 2022; Godsk & Møller, 2025).

One of the most consistent findings identified in the reviewed studies is the positive influence of digital technology on students' learning motivation. Gamification, digital game-based learning, and AI-supported learning environments create enjoyable and personalized learning experiences through interactive multimedia, immediate

feedback, and adaptive instructional activities. These learning environments encourage students to participate more actively, increase their curiosity, and improve their persistence in completing scientific tasks. Consequently, students demonstrate higher levels of intrinsic motivation, which positively contributes to their academic achievement and classroom participation (Coelho et al., 2025; Ortiz-Rojas et al., 2025; Al-Muqbali et al., 2026).

The reviewed studies also demonstrate that digital technology contributes significantly to the development of students' critical thinking skills. Inquiry-based learning, IoT-supported instruction, Virtual Reality (VR), and flipped classroom models encourage students to investigate scientific phenomena, analyze data, formulate hypotheses, evaluate evidence, and solve authentic scientific problems. These instructional approaches promote higher-order thinking by encouraging students to construct knowledge independently rather than relying solely on teacher explanations. Therefore, digital technology supports not only knowledge acquisition but also the development of analytical and problem-solving abilities that are essential in twenty-first-century science education (Arifin et al., 2025; Ay & Dağhan, 2023; Syafruddin et al., 2023).

Another important finding concerns the improvement of students' scientific literacy and learning outcomes. Computational literacy, data literacy, and the Science–Technology–Society (STS) approach provide students with opportunities to interpret scientific information, connect theoretical concepts with real-life situations, and make evidence-based decisions. In addition, digital learning environments facilitate collaboration through virtual laboratories, online discussions, and interactive simulations that strengthen communication skills and scientific inquiry. These findings indicate that digital technology contributes not only to cognitive achievement but also to the development of scientific literacy and digital competence required in modern science education (Braun & Huwer, 2022; Friedrich et al., 2024; Acut & Antonio, 2023; Chávez-Arizala & Soria-Quijaite, 2026).

Although the reviewed studies consistently report positive educational outcomes, several challenges remain in implementing digital technology effectively. Common barriers include limited technological infrastructure, unequal internet access, insufficient teacher digital competence, and variations in students' digital literacy. These findings suggest that technology alone cannot improve learning quality without adequate institutional support, continuous professional development for teachers, and effective instructional planning. Therefore, successful integration of digital technology requires collaboration among teachers, schools, educational institutions, and policymakers to ensure equitable access to technology and sustainable educational innovation (Godsk & Møller, 2025; Ayeni et al., 2024).

Overall, the synthesis demonstrates that digital technology functions not merely as a teaching aid but as an educational innovation that supports interactive, collaborative, and student-centered science learning. By enhancing learning motivation, critical thinking, scientific literacy, engagement, and academic achievement, digital technology contributes significantly to improving the quality of science education. However, its successful implementation depends on the alignment between technological resources, pedagogical strategies, teacher competence, and institutional support. These findings reinforce the importance of integrating digital technology into science education to prepare students with the competencies required in the twenty-first century.

CONCLUSION

This study synthesized fifteen scientific articles published between 2022 and 2026 to examine the integration of digital technology in science learning and its impact on students' learning motivation. The findings indicate that various digital technologies, including Artificial Intelligence (AI), Virtual Reality (VR), Internet of Things (IoT), gamification, digital game-based learning, inquiry-based learning, computational literacy, data literacy, and the Science–Technology–Society (STS) approach, consistently contribute to improving students' learning motivation, critical thinking skills, scientific literacy, engagement, and academic achievement. The reviewed studies demonstrate that digital technology facilitates more interactive, learner-centered, and meaningful science learning experiences while supporting the development of essential twenty-first-century competencies.

Despite these positive findings, the successful implementation of digital technology depends on several factors, including teachers' digital competence, students' readiness, technological infrastructure, and effective instructional design. Therefore, educational institutions should continue to strengthen digital infrastructure and provide continuous professional development for teachers to maximize the educational benefits of digital technology. Since this study is limited to the synthesis of published literature from 2022–2026, future research is recommended to conduct empirical investigations involving larger samples, different educational levels, and diverse learning environments to provide more comprehensive evidence regarding the effectiveness of digital technology in science education.

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