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Development of Digital Interactive Board-Based Learning as a Solution for Elementary School Science Learning

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ABSTRACT

Objective: *This study aimed to develop a Digital Interactive Board-Based Learning system as an innovative instructional medium for elementary science education and to evaluate its validity, practicality, and effectiveness.* ***Method:*** *This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of the Analysis, Design, Development, Implementation, and Evaluation phases. Subject matter experts, instructional media experts, and instructional design experts evaluated product validity. At the same time, practicality and effectiveness were assessed through classroom implementation involving elementary school students using observation sheets, response questionnaires, and learning achievement tests.* ***Results:*** *The validation results indicated that all evaluation aspects achieved the very valid category, with an overall average score of 95.21%. The N-Gain value of 0.69 indicates a moderate-to-high level of learning improvement, demonstrating that the implementation of the Digital Interactive Board-Based Learning (DI-BBL) system significantly enhanced students' conceptual understanding of science. The findings demonstrated that the developed learning system achieved very high levels of validity, practicality, and effectiveness, significantly improving students' learning engagement, conceptual understanding, and critical thinking skills in science learning.* ***Novelty:*** *The novelty of this study lies in the development of an integrated Digital Interactive Board-Based Learning system that combines interactive multimedia, inquiry-based exploration, digital assessment, immediate feedback, and reflective learning within a single instructional environment, thereby supporting the implementation of the Merdeka Curriculum and fostering twenty-first-century competencies among elementary school students.*

INTRODUCTION

Digital transformation has become one of the primary drivers of educational paradigm shifts in the twenty-first century (Muzafar & Ahmad, 2026; Pertiwi et al., 2026). The rapid advancement of information and communication technologies (ICT) has not only changed the way people access information but has also fundamentally transformed how teachers design, implement, and evaluate learning processes. The integration of digital technologies into education enables more effective, adaptive, innovative, and student-centered learning by providing interactive, flexible, and personalized learning experiences that accommodate diverse learning needs. Beyond improving instructional quality, digital technology also plays a crucial role in fostering twenty-first-century competencies, including critical thinking, creativity, communication, collaboration, digital literacy, and problem-solving skills (Pertiwi et al., 2026). Numerous studies have demonstrated that the appropriate integration of digital technologies significantly enhances student engagement, learning effectiveness, and academic achievement (Bond et al., 2024; OECD, 2023; UNESCO, 2023). In Indonesia, the implementation of the Merdeka Curriculum further emphasizes the strategic role of digital technology in

supporting student-centered learning and strengthening the development of the Pancasila Student Profile. Consequently, teachers are expected to develop and utilize innovative digital learning media that make classroom instruction more meaningful, contextual, and relevant to contemporary educational demands.

Science education at the elementary school level is characterized by inquiry-based learning that encourages students to construct knowledge through observing, investigating, classifying, communicating, and drawing conclusions from natural phenomena. Science learning is intended not only to develop conceptual understanding but also to cultivate scientific process skills, critical thinking, problem-solving abilities, and scientific attitudes. However, many elementary science topics involve abstract concepts such as natural phenomena, ecosystems, energy transformation, and biological systems that are difficult for young learners to observe directly (Prayoga et al., 2025). As a result, students often experience difficulties in understanding scientific concepts when instruction relies primarily on lectures and printed textbooks. Therefore, effective science instruction requires learning media capable of visualizing abstract concepts through images, animations, videos, simulations, and interactive activities, allowing students to connect scientific theories with authentic learning experiences. Previous studies have consistently reported that interactive digital learning media significantly improve conceptual understanding, scientific literacy, motivation to learn, and higher-order thinking skills among elementary school students (Chen et al., 2022; Hwang et al., 2022; Lai et al., 2023).

Despite the rapid advancement of digital transformation, science instruction in elementary schools continues to face several challenges. Classroom observations indicate that teaching practices remain largely dominated by teacher-centered lectures, printed textbooks, worksheets, and simple presentation slides, resulting in limited student participation during the learning process. Such instructional approaches provide insufficient opportunities for students to engage in exploration, scientific inquiry, collaborative discussion, and problem-solving activities. Consequently, students tend to memorize scientific concepts rather than construct meaningful conceptual understanding through active learning experiences. This condition also contributes to limited development in critical thinking, scientific communication, creativity, and digital literacy. In addition to the limited availability of innovative instructional media, another major challenge is teachers' insufficient capacity to integrate digital technology effectively into student-centered instructional strategies (Riza et al., 2024; Safitri et al., 2025). These findings are consistent with previous research suggesting that successful digital transformation depends not only on technological infrastructure but also on teachers' pedagogical competence in integrating technology into meaningful learning experiences (OECD, 2023; Rahmawati et al., 2023; Wahyuni et al., 2024).

A digital interactive board represents one of the most promising technological innovations for enhancing science instruction in elementary schools. This technology enables teachers to integrate various instructional components-including text, images, animations, videos, simulations, interactive quizzes, educational games, and

collaborative learning activities-within a single digital learning environment (Sailer & Homner, 2020). Such integration allows students to actively interact with learning materials through exploration, observation, discussion, experimentation, and collaborative problem-solving. Moreover, abstract scientific concepts become easier to understand because students can observe dynamic visualizations and interactive simulations that represent real-world scientific phenomena (Hasanah & Sudaira, 2021). Digital interactive boards also facilitate formative assessment by providing immediate feedback on students' learning progress throughout the instructional process. Previous studies have demonstrated that interactive digital boards improve students' motivation, engagement, academic achievement, critical thinking, and collaborative learning skills in science education (Chen et al., 2022; García-Valcárcel & Martín del Pozo, 2022; Hwang et al., 2022; König et al., 2023).

Recent developments in educational technology research indicate a substantial increase in the development of digital learning media for elementary science education. Various innovations have been introduced, including electronic modules, interactive flipbooks, animated instructional videos, Android-based applications, virtual laboratories, augmented reality, and gamification-based learning environments (Liu et al., 2020; Maas & Hughes, 2020). Existing studies consistently report that these digital learning media positively influence students' academic achievement, learning motivation, scientific literacy, and higher-order thinking skills. A systematic review conducted by Prayoga et al. (2025) concluded that interactive digital learning media create more effective learning experiences by integrating visual, auditory, and interactive instructional elements. Similarly, Putri et al. (2024) reported that interactive digital media significantly improve students' conceptual understanding of science, while Utami et al. (2025) highlighted that technology integration strengthens student engagement throughout the learning process. These findings indicate that digital learning media have become an essential component of contemporary science education in elementary schools.

Nevertheless, a review of previous studies reveals an important research gap. Although numerous studies have developed digital instructional media for elementary science education, most have focused on developing a single type of learning medium or evaluating its effectiveness in improving learning outcomes (Boda et al., 2021). Only a limited number of studies have integrated multiple instructional components, including learning content, multimedia resources, simulations, interactive activities, formative assessment, and learning reflection, within a comprehensive digital learning environment. Consequently, there remains a need to develop an integrated instructional platform that combines these components into a coherent, interactive, and student-centered learning system.

To address this gap, the present study develops digital interactive board-based learning as an integrated learning platform for elementary science education using the ADDIE instructional design model (Latip, 2022). Unlike previous studies that primarily focused on individual digital media, the proposed platform integrates science learning

materials, instructional videos, animations, interactive simulations, exploratory learning activities, digital quizzes, formative assessments, and reflective learning tasks into a single interactive learning environment (Fu'adah & Ratnaningrum, 2024). This integrated approach is expected to enhance students' conceptual understanding, learning engagement, critical thinking, collaboration, and digital literacy while supporting the implementation of the Merdeka Curriculum and twenty-first-century learning competencies. A comparison between previous studies and the present research is relevant.

Previous studies have consistently demonstrated the positive impact of digital learning media on elementary science education. Widodo and Widiyanti (2021) reported that interactive multimedia significantly improved students' science learning outcomes; however, their study was limited to multimedia presentation without integrating digital assessment or collaborative learning activities. Similarly, Rahmawati et al. (2023) found that digital learning media enhanced students' motivation and classroom engagement, although the learning process did not incorporate interactive simulations, differentiated instruction, or reflective learning activities. Putri et al. (2024) further showed that interactive learning media improved students' conceptual understanding of science but did not integrate instructional design with authentic assessment.

More recently, Prayoga et al. (2025) concluded, through a systematic literature review, that digital learning media positively influenced the quality of science learning. However, their study was limited to synthesizing existing literature without developing or validating a learning product. Building upon these findings, the present study develops an integrated digital interactive board-based learning system that combines science content, animations, videos, simulations, exploratory activities, interactive quizzes, digital assessment, reflective learning, and differentiated instruction within the ADDIE instructional design framework, thereby addressing several limitations identified in previous studies.

Previous studies have made significant contributions to the development of digital learning media, particularly in improving students' academic achievement, learning motivation, and engagement. However, most existing studies remain limited because they primarily focus on developing instructional media as tools for content delivery or evaluating their effectiveness without integrating exploratory learning activities, interactive simulations, digital assessments, differentiated instruction, and reflective learning within a unified instructional framework. This limitation indicates a clear research gap that necessitates the development of a more comprehensive and integrated learning model.

Addressing this gap, the present study develops Digital Interactive Board-Based Learning (DI-BBL) as an integrated instructional system that combines science learning materials, scientific concept visualization, instructional videos, interactive simulations, exploratory learning activities, digital quizzes, formative assessment, and learning reflection within a single digital platform. This integrated learning environment is expected to provide a more interactive, student-centered, and meaningful learning

experience while supporting the implementation of the Merdeka Curriculum and fostering the development of twenty-first-century competencies.

The novelty of this study lies in the development of digital interactive board-based learning not merely as a digital instructional medium but as a comprehensive instructional system designed using the ADDIE instructional design model. The developed platform integrates science learning content, visual representations of scientific concepts through images, animations, instructional videos, interactive simulations, exploratory learning activities, digital quizzes, formative assessments, and reflective learning into a single cohesive learning environment tailored to the characteristics of elementary school students and aligned with the principles of the Merdeka Curriculum. Unlike previous studies that primarily focused on the development of isolated digital media or the partial evaluation of instructional effectiveness, this study integrates digital technology with active learning strategies, differentiated instruction, and authentic assessment to create a more comprehensive, interactive, and student-centered learning experience. Consequently, this study is expected to contribute not only to the advancement of digital learning media for elementary science education but also to enrich the growing body of knowledge on digital transformation in primary education.

Accordingly, this study aims to develop digital interactive board-based learning as an innovative solution for improving the quality of science education in elementary schools through the ADDIE instructional design model, which consists of the analysis, design, development, implementation, and evaluation phases. The developed product is expected to meet the criteria of validity, practicality, and effectiveness, as demonstrated through expert validation, positive responses from teachers and students, and successful classroom implementation. Furthermore, the proposed learning system is expected to enhance students' learning engagement, conceptual understanding of science, motivation to learn, critical thinking, collaboration, communication, and digital literacy skills. Ultimately, this study contributes not only by developing an innovative, interactive, board-based learning system but also by offering an alternative instructional design that supports the implementation of the Merdeka Curriculum and promotes digital transformation in elementary education.

RESEARCH METHOD

This study employed a Research and Development (R&D) approach to develop digital interactive board-based learning as an instructional solution for improving the quality of science education in elementary schools. The R&D approach was selected because the study was designed not only to investigate instructional problems but also to develop an educational product that can be effectively implemented in classroom practice. The product developed in this study is a digital interactive board-based learning system that integrates science learning materials, interactive multimedia, exploratory learning activities, practice exercises, and digital assessments into a single instructional platform. The following is the design of the ADDIE model as seen in Figure 1.

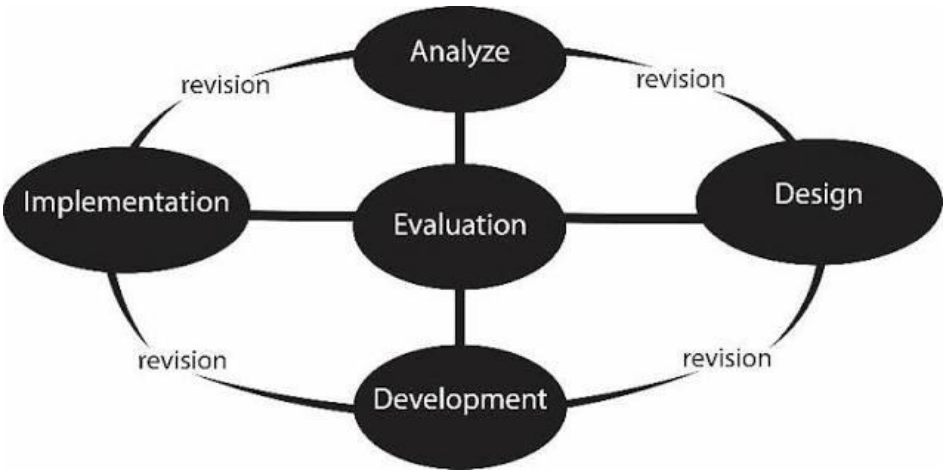

Figure 1. ADDIE model

The instructional product was developed using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) proposed by Branch (2009). The ADDIE model was selected because it provides a systematic, flexible, and widely accepted framework for developing technology-based instructional media and learning systems (Motovu et al., 2023; Zhofir et al., 2025). Each phase of the model was conducted sequentially to ensure that the developed product achieved high levels of validity, practicality, and effectiveness. The stages of developing the Digital Interactive Board-Based Learning system implemented in this study are presented in Table 1.

Table 1. Stages of developing the digital interactive board-based learning system using the ADDIE model

Stages	Development Activities
Analysis	Identify instructional needs, students' characteristics, science content characteristics, learning problems, teachers' needs, and the availability of technological facilities in schools. Curriculum analysis is conducted to determine the Learning Outcomes (CP) and Learning Objectives (TP) in accordance with the Merdeka Curriculum.
Design	Develop the initial instructional design, including learning objectives, selection of science learning materials, media interface structure, interactive learning activities, research instruments, and learning assessment plans.
Development	Develop the Digital Interactive Board-Based Learning system using appropriate software tools, conduct expert validation involving subject matter experts, instructional media experts, and instructional design experts, and revise the product based on the validators' recommendations.
Implementation	Implement the developed learning system in elementary school science classrooms to evaluate its practicality and effectiveness through classroom observations, user response questionnaires, and learning achievement tests.
Evaluation	Conduct both formative and summative evaluations to assess the quality of the developed product in terms of validity, practicality, effectiveness, student learning activities, and users' responses.

The first phase of the development process was the analysis stage, which aimed to identify the requirements for developing digital interactive board-based learning for elementary school science instruction. This phase involved analyzing students' characteristics, teachers' instructional needs, the characteristics of science content, existing classroom learning conditions, and the availability of technological facilities in schools. A needs assessment was conducted to identify instructional problems, particularly the low level of student engagement resulting from the continued use of conventional instructional media. In addition, curriculum analysis was carried out to determine the expected learning outcomes, learning objectives, appropriate science content, and competencies to be developed in accordance with the principles of the Merdeka Curriculum. The findings of this analysis served as the foundation for designing a digital interactive board-based learning system that addressed the instructional needs of both teachers and students.

The second phase was the design stage, which focused on developing the initial blueprint of the digital interactive board-based learning system. This phase included formulating learning objectives, selecting science learning materials, designing the user interface, developing interactive learning activities, and constructing assessment instruments. The instructional design was based on the principles of active learning, constructivist learning, and student-centered instruction. The digital interactive board was designed to integrate various instructional components, including visual learning materials, illustrative images, instructional videos, science concept animations, interactive simulations, discussion activities, interactive quizzes, and digital assessments. In addition, research instruments were developed during this stage, including expert validation sheets, teacher and student response questionnaires, classroom observation sheets, and learning achievement tests.

During the development phase, the initial instructional design was transformed into a prototype of the digital interactive board-based learning system for elementary science education. The prototype was developed as an interactive learning environment that integrated visual learning materials, animations, instructional videos, exploratory activities, interactive quizzes, and digital assessments into a single, cohesive platform. The prototype was designed by considering the characteristics of elementary school students, who require engaging visual interfaces, simple navigation, and interactive learning activities that actively involve them in constructing scientific understanding.

The prototype was designed not merely as an instructional aid for presenting learning content but as a comprehensive digital learning environment that supports observation, exploration, discussion, experimentation, and reflective learning. The platform consists of several main components, including a home page, learning objectives, instructional materials, exploratory learning activities, interactive quizzes, learning assessments, and reflection activities. Each component was systematically designed to promote more interactive, contextual, and student-centered science learning while facilitating meaningful learning experiences for elementary school students. The prototype learning design based on a digital interactive whiteboard is shown in Figure 2.

Figure 2. Prototype design of digital interactive whiteboard-based learning media for elementary school science instruction

Figure 2 illustrates the prototype design of the digital interactive board-based learning system developed in this study. The main interface provides a user-friendly navigation menu that enables users to access various instructional features efficiently. The learning content is designed by integrating multimedia elements, including illustrations, animations, and interactive simulations, to facilitate students' understanding of abstract scientific concepts. The exploratory learning feature provides opportunities for students to observe, investigate, connect scientific concepts, and solve problems through interactive learning activities.

The interactive quiz and digital assessment features serve both formative and summative assessment purposes. Through these features, students receive immediate feedback on their learning performance, while teachers can continuously monitor students' conceptual understanding throughout the instructional process. In addition, the learning reflection component is designed to encourage students to summarize the concepts they have learned and relate them to scientific phenomena encountered in everyday life.

Following the development of the prototype, the product was evaluated by subject matter experts, instructional media experts, and instructional design experts to determine its feasibility before classroom implementation. Feedback and recommendations from the expert validators were used to revise and improve the product, ensuring high quality in terms of content accuracy, interface design, interactivity, and usability.

The fourth phase, implementation, involved the application of the Digital Interactive Board-Based Learning system in elementary school science classrooms. This phase aimed

to examine the practicality and effectiveness of the developed product in authentic learning settings. During implementation, teachers used the digital interactive board as the primary instructional medium. At the same time, students actively participated in observing, exploring, discussing, solving scientific problems, completing interactive quizzes, and participating in digital learning assessments. Implementation data were collected through classroom observations, teacher and student response questionnaires, and pre-test and post-test learning achievement assessments. These data were analyzed to evaluate the product's effectiveness in improving student engagement, learning motivation, conceptual understanding, and critical thinking skills in science learning.

The final phase, evaluation, was conducted to determine the overall quality of the developed instructional product. Both formative and summative evaluations were performed. Formative evaluation was carried out throughout each stage of the development process based on expert feedback and the results of limited-scale trials to refine the product continuously. Summative evaluation was conducted after classroom implementation to assess the effectiveness of the digital interactive board in elementary science instruction. The evaluation focused on product validity, practicality, learning effectiveness, student learning activities, and users' overall responses to the developed learning system.

The participants of this study consisted of elementary school students who served as the primary users of the digital interactive board-based learning system. Classroom teachers or science teachers participated in evaluating the practicality and usability of the developed product. Furthermore, expert validators—including subject matter experts, instructional media experts, and instructional design experts—were involved in assessing the feasibility of the instructional product before its classroom implementation.

Data were collected using multiple techniques, including classroom observation, interviews, questionnaires, documentation, and learning achievement tests. Classroom observations were conducted to examine students' learning activities during instruction. Interviews were carried out to identify teachers' instructional needs and challenges in elementary science teaching. Questionnaires were administered to obtain expert validation data as well as teachers' and students' responses regarding the developed learning system. Learning achievement tests were employed to evaluate the effectiveness of the digital interactive board in improving students' conceptual understanding of science.

The collected data were analyzed using both quantitative and qualitative approaches. Quantitative data were obtained from expert validation scores, user response questionnaires, and students' learning achievement test results. Validation and user response data were analyzed using percentage scores to determine the validity and practicality levels of the developed product. Learning achievement data were analyzed by comparing students' performance before and after the implementation of the digital interactive board-based learning system. Qualitative data were obtained from comments, suggestions, and recommendations provided by expert validators and users throughout the development process (Fauzan et al., 2025). These qualitative findings served as the

basis for revising and refining the product to ensure that the developed digital interactive board-based learning system achieved optimal quality and was suitable for implementation in elementary science.

RESULTS AND DISCUSSION

Results

Analysis Results

The analysis phase was conducted to identify the instructional needs of elementary school science education as the foundation for developing the digital interactive board-based learning system. This phase involved classroom observations, teacher interviews, curriculum analysis, and an analysis of students' characteristics. The findings indicated that science instruction required more innovative learning media capable of increasing student engagement, facilitating exploratory learning activities, and supporting the implementation of the Merdeka Curriculum. The results of the analysis can be seen in Table 2 below.

Table 2. Results of needs analysis

Analysis Aspect	Findings
Learning conditions	IPA learning was still dominated by lectures and textbooks so students' learning activities were not optimal.
Learning media	Teachers had utilized PowerPoint presentations and learning videos, but digital interactive boards had not yet been implemented.
Student characteristics	Students understood concepts more easily through visualization, animation, simulation, and interactive activities.
Teacher needs	Teachers required an integrated learning medium that combined learning materials, interactive activities, digital assessment, and feedback within a single platform.
Curriculum analysis	Learning materials were developed based on the Learning Outcomes (CP) and Learning Objectives (TP) of the Merdeka Curriculum and adjusted to elementary science characteristics.

As presented in Table 2, elementary school science instruction remains largely dependent on conventional instructional media, which are insufficient to accommodate students' learning needs for active participation, exploration, and conceptual visualization. These findings served as the basis for designing the Digital Interactive Board-Based Learning system, which integrates instructional content, learning videos, interactive simulations, digital quizzes, assessments, and reflective learning activities within a single instructional platform.

Design Results

The design phase resulted in the initial interface and instructional framework of the Digital Interactive Board-Based Learning system, developed based on the findings of the needs analysis. The instructional design was grounded in the principles of constructivist and student-centered learning, positioning students as active participants in constructing scientific knowledge. Each interface component and navigation menu was systematically

organized to provide a coherent learning sequence, beginning with learning orientation and continuing through content exploration, interactive activities, formative assessment, and concluding with learning evaluation and reflection. The interface design results can be seen in Figure 3 below.

Figure 3. User interface design of the digital interactive board

As illustrated in Figure 3, the developed digital interactive board-based learning system consists of nine main components: the welcome page, learning objectives, science learning materials, exploratory learning activities, instructional videos, interactive simulations, digital quizzes, learning assessments, and learning reflection. The integration of these multimedia components was designed to facilitate students' understanding of abstract scientific concepts while simultaneously enhancing their learning motivation, active participation, and critical thinking skills throughout the instructional process.

Development Results

The Development phase produced a functional prototype of the digital interactive board-based learning system, which subject-matter, instructional media, and instructional design experts subsequently evaluated. The validation process was conducted to determine the feasibility and quality of the developed product based on several evaluation criteria, including content accuracy, language appropriateness, interface design, interactivity, usability, and instructional design quality. The validation results can be seen in Table 3.

Table 3. Validation results based on assessment aspects

Assessment Aspect	Material Expert	Media Expert	Learning Design Expert	Category
Content suitability	95.00	–	–	Very Valid
Language	94.50	–	–	Very Valid
Visual appearance	–	97.00	–	Very Valid
Interactivity	–	96.50	–	Very Valid
Ease of use	–	95.25	94.75	Very Valid
Learning design	–	–	94.38	Very Valid
Average	95.00	96.25	94.38	Very Valid

The validation results indicated that all evaluation aspects achieved the very valid category, with an overall average score of 95.21%. These findings demonstrate that the developed digital interactive board-based learning system satisfied the required standards for content quality, instructional presentation, visual design, interactivity, and instructional design, indicating that it was suitable for classroom implementation following minor revisions based on the experts' recommendations. The revisions included improving the navigation system, adding user guidelines, refining the icon design, standardizing scientific terminology, and incorporating reflective learning activities at the end of each lesson.

Implementation Results

The Implementation phase was conducted through classroom trials of the digital interactive board-based learning system in elementary school science lessons. Classroom observations revealed that students actively participated throughout the learning process. They engaged enthusiastically in observing multimedia content, exploring interactive learning activities, participating in group discussions, completing interactive quizzes, and responding to digital assessments. The use of the digital interactive board created a more engaging and student-centered learning environment, encouraging students to actively construct scientific knowledge through exploration, interaction, and collaborative learning experiences. The implementation results can be seen in Table 4.

Table 4. Students' learning activities during implementation

Activity Indicator	Observation Result
Observing digital learning materials	Very Good
Participating in group discussions	Very Good
Operating the digital interactive board	Very Good
Completing interactive quizzes	Very Good
Presenting discussion results	Good
Conducting learning reflection	Very Good

Based on the observation results presented in Table 4, the implementation of the digital interactive board-based learning system significantly increased students' engagement throughout each stage of the learning process. Students became more actively involved in observing instructional materials, participating in group discussions, interacting with the digital learning platform, completing interactive quizzes, presenting the results of

collaborative activities, and engaging in reflective learning. These findings indicate that the developed learning system successfully promotes a student-centered learning environment and is well aligned with the principles of the Merdeka Curriculum.

The practicality of the developed learning system was subsequently evaluated using teacher and student response questionnaires to assess its usability, ease of implementation, and overall acceptance in classroom practice; these results are shown in Table 5.

Table 5. Practicality results

Respondent	Percentage	Category
Teacher	97.14	Very Practical
Students	95.32	Very Practical
Average	96.23	Very Practical

The practicality test results indicated that both teachers and students expressed highly positive responses toward the use of the developed digital interactive board-based learning system. Teachers reported that the learning system was easy to use and effectively supported the delivery of science instruction. At the same time, students perceived the platform as engaging, user-friendly, and helpful in facilitating their understanding of scientific concepts. These findings suggest that the developed learning system is highly practical and can be readily implemented in elementary school science classrooms. The effectiveness of the developed learning system was subsequently evaluated by comparing students' pre- and post-test scores to assess its impact on students' conceptual understanding of science following implementation of the digital interactive board-based learning system. The learning outcomes were 63.52 for the pre-test and 88.71 for the post-test. The N-Gain value of 0.69 indicates a moderate-to-high level of learning improvement, demonstrating that the implementation of the digital interactive board-based learning system significantly enhanced students' conceptual understanding of science.

Discussion

The findings demonstrate that the developed digital interactive board-based learning system meets the criteria of validity, practicality, and effectiveness as an instructional medium for elementary science education. The high validation scores obtained for content quality, language appropriateness, visual design, interactivity, and instructional design indicate that the learning system was developed in accordance with the characteristics of elementary school students and the instructional requirements of the Merdeka Curriculum. The integration of multiple multimedia components, including text, images, animations, instructional videos, interactive simulations, digital quizzes, assessments, and reflective learning activities, provided students with a more meaningful learning experience than conventional instructional media (Efe & Umdu, 2022; Hussein et al., 2025).

These findings are consistent with Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2021), which proposes that learning becomes more effective when information is

presented through a combination of verbal and visual representations rather than through text or verbal explanations alone. According to this theory, learners process information through two complementary cognitive channels: the visual and verbal processing systems. Consequently, presenting science content through a digital interactive board enables students to understand abstract scientific concepts, such as natural phenomena, energy transformation, and ecosystems, more effectively by utilizing animations, illustrations, and interactive simulations that facilitate meaningful cognitive processing.

The results also support the findings of Hwang et al. (2022), who reported that integrating digital technologies into classroom instruction enhances learning interaction, student engagement, and instructional effectiveness. In the present study, the digital interactive board functioned not merely as a content delivery medium but as an interactive learning environment that enabled students to explore scientific concepts, complete interactive quizzes, participate in collaborative discussions, and receive immediate formative feedback (Koc & Kanadli, 2025). These characteristics demonstrate that digital technology serves as a facilitator of active learning rather than simply as a presentation tool.

Classroom implementation further revealed that the use of the digital interactive board substantially increased students' participation throughout the learning process. Students were more actively involved in observing instructional materials, discussing scientific concepts, operating the digital learning platform, completing interactive quizzes, and engaging in reflective learning activities. These findings indicate a pedagogical shift from teacher-centered learning toward student-centered learning, which aligns closely with the principles of the Merdeka Curriculum, emphasizing exploration, collaboration, contextual learning, and active student participation.

The findings are also consistent with the review conducted by Bond et al. (2024), which concluded that digital transformation in education positively influences student participation, motivation, collaboration, and engagement when technology is integrated with appropriate pedagogical strategies. Therefore, the effectiveness of the developed learning system cannot be attributed solely to the use of digital technology but also to the instructional design that systematically integrates exploratory learning, formative assessment, and reflective learning activities within a cohesive instructional framework.

The learning system also demonstrated a high level of practicality, achieving the Very Practical category based on teachers' and students' evaluations. Teachers reported that integrating learning materials, instructional activities, assessments, and immediate feedback into a single platform simplified classroom management and instructional delivery. Meanwhile, students responded positively because the platform provided an attractive interface, intuitive navigation, and engaging interactive activities that made science learning more enjoyable. These findings suggest that digital learning media featuring simple and interactive user interfaces significantly improve usability and user acceptance in elementary education (García-Valcárcel & Pozo, 2022).

The effectiveness of the developed learning system was further demonstrated by the significant improvement in students' learning achievement following its implementation. The increase in average post-test scores, together with the N-Gain value of 0.69, indicates that the digital interactive board effectively enhanced students' conceptual understanding of science. This improvement in learning outcomes was supported by increased student engagement during classroom implementation, particularly in observation activities, collaborative discussions, interactive quiz completion, and reflective learning.

These results indicate that the developed learning system has a significant positive impact on student learning outcomes (Asmelawati et al., 2026). Furthermore, the improvement in conceptual understanding is supported by increased active student engagement during the learning process, as evidenced by participation in observation activities, collaborative discussions, interactive quizzes, and learning reflections. Thus, this study finds that integrating digital interactive whiteboards not only enhances students' cognitive achievement but also fosters more active, interactive, and student-centered learning. Furthermore, the results indicate that the developed learning system contributes to the development of twenty-first-century competencies. Collaborative discussions, digital quizzes, group presentations, and reflective learning activities fostered students' critical thinking, communication, collaboration, creativity, and digital literacy. These competencies constitute essential learning outcomes within the Merdeka Curriculum and are increasingly recognized as fundamental skills required to meet the challenges of digital transformation in education.

Compared with previous studies that primarily focused on developing a single type of digital instructional medium, this research makes a significant contribution by integrating multiple instructional components into a comprehensive learning system. Rather than functioning solely as a medium for presenting instructional content, the developed platform combines instructional videos, interactive simulations, exploratory learning activities, digital quizzes, assessments, and reflective learning within a single digital interactive board-based learning environment. This comprehensive integration enables a more systematic, interactive, and student-centered instructional process while providing richer and more meaningful learning experiences. The findings have important implications for educational practice. Digital interactive board-based learning has considerable potential to serve as an innovative instructional solution for elementary science education in support of ongoing digital transformation initiatives. The developed product provides teachers with an integrated instructional platform that aligns with the characteristics of elementary school learners and the pedagogical principles of the Merdeka Curriculum. Beyond improving learning outcomes, the system also promotes the development of twenty-first-century competencies, suggesting that it can be adapted for other subject areas and educational levels to support broader technology-enhanced learning initiatives.

CONCLUSION

Fundamental Findings: This study successfully developed a digital interactive board-based learning system with very high validity, practicality, and effectiveness, as evidenced by expert validation, user responses, and classroom implementation. The study found that implementing the digital interactive board-based learning system effectively improved students' conceptual understanding of science, as reflected in the increase in the average score from 63.52 (pre-test) to 88.71 (post-test), with an N-Gain of 0.69, indicating a moderate-to-high improvement. The integration of instructional content, animations, videos, interactive simulations, digital assessments, and immediate feedback within a single learning platform significantly enhanced students' engagement, conceptual understanding, and critical thinking skills. **Implication:** The findings provide both theoretical and practical implications for technology-enhanced learning in elementary education. Theoretically, this study strengthens the understanding that integrating interactive digital technology can improve learning quality by providing meaningful learning experiences. Practically, the developed learning media offer teachers an innovative instructional alternative for implementing science learning aligned with the Merdeka Curriculum. Furthermore, the study may serve as a reference for schools and educational policymakers in promoting digital learning ecosystems that foster twenty-first-century competencies. **Limitation:** The developed product was implemented only within a specific science topic and involved a limited number of participants; therefore, the generalizability of the findings should be interpreted with caution. In addition, the effectiveness evaluation focused on short-term implementation and did not examine long-term learning retention or sustained improvement in higher-order thinking skills. **Future Research:** Future studies are recommended to implement the digital interactive board across different science topics, educational levels, and larger, more diverse participant populations. Further research may also integrate emerging technologies such as Artificial Intelligence (AI), learning analytics, and adaptive learning to provide more personalized learning experiences. Longitudinal studies are also needed to investigate the long-term effects of digital interactive board-based learning on knowledge retention, higher-order thinking skills, creativity, collaboration, and the development of twenty-first-century competencies.

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AUTHOR CONTRIBUTIONS

Nofa Arista: Conceptualization, Methodology, Investigation, Development of Digital Interactive Board-Based Learning, Development of Research Instruments, Data Collection, Formal Analysis, Visualization, Writing – Original Draft. **Enny Susiyawati:** Conceptualization, Research Design, Methodology, Validation, Supervision, Review and

Editing. **Binar Kurnia Prahani:** Methodology, Validation, Data Interpretation, Supervision, Critical Review, Final Approval of Manuscript. All authors actively contributed to every stage of this research, critically reviewed the manuscript, and approved the final version for publication.

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 during the preparation of this manuscript. ChatGPT (OpenAI) was utilized to support language refinement, grammar improvement, academic writing enhancement, and translation between Indonesian and English. Microsoft Word was used for manuscript preparation and formatting, while Mendeley Reference Manager was employed for citation management and reference formatting in accordance with APA 7th Edition. All AI-assisted outputs were critically reviewed, verified, revised, and validated by the authors to ensure the accuracy, originality, academic integrity, and scientific quality of the manuscript. The authors assume full responsibility for the content, interpretation, and conclusions presented in this article.

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