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Digital-Based Deep Learning in Elementary Education: Implementation, Supporting Ecosystem, and Sustainability Challenges

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ABSTRACT

The integration of digital technology into elementary education creates opportunities for more contextual, collaborative, and meaningful learning. However, limited evidence explains how digital tools, pedagogical practices, school leadership, and organizational support interact to facilitate deep learning in primary schools. This study aimed to describe the implementation of digital-based deep learning and identify the factors supporting and hindering its sustainability. A descriptive qualitative design was employed involving one principal and four teachers selected through purposive sampling. Data were collected through in-depth interviews, four classroom observations, and document analysis, then analyzed through coding, categorization, theme development, data display, and conclusion verification. Trustworthiness was strengthened through source and technique triangulation. The findings reveal that digital-based deep learning emerged through the interaction of a supportive digital school ecosystem, purposeful technology integration, and contextual learning activities. Chromebooks, interactive displays, Google Classroom, and Google Workspace for Education were used to support collaborative data collection, authentic tasks, presentations, and classroom interaction. Observed activities reflected characteristics of mindful learning through explicit learning objectives and reflection; meaningful learning through authentic tasks, problem solving, and connections with real-world contexts; and joyful learning through curiosity, collaboration, and active student participation. Implementation was further supported by digital-oriented school leadership, peer mentoring, teacher learning communities, infrastructure, stakeholder support, and regular monitoring and evaluation. Challenges included internet instability, device maintenance, electricity constraints, and varying levels of teacher readiness. Teachers responded by combining digital and conventional learning and preparing alternative activities when technical disruptions occurred. These findings indicate that sustainable digital-based deep learning depends not merely on technology availability but on the alignment of digital infrastructure, pedagogical capacity, collaborative school culture, leadership, stakeholder support, and continuous and systematic evaluation practices.

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INTRODUCTION

Deep learning is considered a relevant approach for addressing the educational challenges of the 21st century. Kemendikdasmen (2025) explains in an academic paper on deep learning released by the Ministry of Basic and Secondary Education that the concept is defined as an approach that elevates the learner by emphasizing the creation of a learning atmosphere and a process that is mindful, meaningful, and joyful, engaging the body, brain, and heart holistically. The concept of Deep Learning rests on three main principles: Mindful Learning, wherein students possess full awareness of what they are learning, why it is important, and how it relates to their lives; and Meaningful Learning, which emphasizes a deep understanding of concepts over mere rote memorization.

Conceptual and procedural knowledge are linked in a logical and applicable manner. "Joyful Learning" refers to an educational atmosphere designed to be enjoyable, to liberate students' potential, and to foster curiosity without excessive pressure. In this study, digital-based deep learning is defined as the integration of digital technology into the learning process serving not merely as a medium for content delivery, but also as a means to facilitate the realization of deep learning characteristics (Feriyanto & Anjariyah, 2024). Operationally, the implementation of digital-based deep learning is identified through instructional practices that reflect three key, observable dimensions during the learning process. Drawing upon the deep learning characteristics outlined in the Academic Paper on Deep Learning, these three dimensions are identified through indicators that can be observed during the learning process. The "mindful" dimension is demonstrated by students' understanding of learning objectives, their conscious engagement in learning activities, and their ability to reflect on the learning process and outcomes. The "meaningful" dimension is reflected in students' ability to connect material with prior experiences or knowledge, apply concepts in real-world contexts, solve problems, and complete authentic tasks. Meanwhile, the "joyful" dimension is evidenced by the emergence of curiosity, voluntary active participation, interactions that foster psychological safety, and positive student engagement throughout the learning process (Casinader, 2021). Thus, the presence of digital tools is not viewed as an indicator of deep learning in itself, but rather as a means to facilitate the realization of mindful, meaningful, and joyful characteristics when appropriately integrated into instructional strategies. These indicators serve as a foundation for interpreting classroom observation results and interview data regarding the implementation of digital-based deep learning. This approach focuses on four key learning experiences undertaken by students: comprehensively understanding concepts, applying knowledge in new situations or real-world contexts, and reflecting on their learning processes and outcomes (Rahmawati et al., 2025).

Deep learning focuses on developing skills such as critical thinking, problem solving, creativity, communication, and collaboration (Rahim et al., 2023). These competencies form the foundation of 21st-century education, preparing learners to navigate change and effectively address various challenges. Furthermore, deep learning in primary schools goes beyond mere learning outcomes; it emphasizes how students acquire broad and enduring understanding aligned with their cognitive developmental stages. Deep learning has become increasingly vital in 21st-century education due to its emphasis on cultivating critical thinking, problem-solving, creativity, communication, and collaboration (Thornhill-Miller et al., 2023). In the context of digital transformation, the implementation of deep learning is bolstered by the use of technology, enabling students to engage in learning experiences that are more interactive, contextual, and meaningful. Integrating digital tools not only facilitates access to diverse learning resources but also fosters active student engagement in the learning process (Ye & Xu, 2023). Sitepu (2021) explains that, alongside advancements in information technology, digital-based learning has emerged as an effective method for supporting the implementation of deep learning. Digital technology offers teachers the opportunity to design learning experiences that are more interactive, contextual, and collaborative, provided it is integrated in alignment with learning objectives, pedagogical strategies, and student characteristics. Consequently, the use of technology does not automatically result in deep learning; rather, it depends on how the technology is employed to support a learning process that is mindful, meaningful, and joyful (Siregar et al., 2025). When instruction is digitally designed, digital technology can enhance the learning experience, improve conceptual understanding, and boost student engagement in the learning process (Riady, 2021). However, digital-based deep learning still faces numerous challenges when implemented in primary schools (Rosita & Elviera, 2025; Triyunita et al., 2025). Studies indicate that technology is often used merely as a tool for delivering content and has not yet been effectively and comprehensively integrated into learning strategies that foster critical thinking (Sugiarto et al., 2023; Wirdayani et al., 2023).

Various studies have demonstrated that the use of digital technology can enhance access, interactivity, and flexibility in learning, while also providing teachers with opportunities to create

more contextual and learner-centered educational experiences (Adila & Rodiyah, 2024; Riady, 2021; Sitepu, 2021). Meanwhile, deep learning has been shown to foster critical thinking, problem-solving, self-reflection, and creativity, as well as the ability to connect knowledge with real-life situations (Kementerian Pendidikan Dasar dan Menengah, 2025; Rahmawati et al., 2025). Although research has addressed both the use of digital technology and deep learning, most studies have focused on the effectiveness of digital media, the enhancement of digital literacy, or deep learning pedagogical strategies in isolation (Adila & Rodiyah, 2024; Ardimiati et al., 2026). Consequently, there is limited research describing how digital tools, pedagogical activities, school leadership, teacher collaboration, and school ecosystem support interact to facilitate the implementation of deep learning at the primary school level. In particular, there is limited research describing the implementation mechanisms that show how various digital learning tools and platforms are integrated into learning activities to foster mindful, meaningful, and joyful learning at the primary school level. Yet, effective technology integration requires alignment among technological, pedagogical, and content aspects, as outlined in the TPACK framework (Mishra & Koehler, 2006). Therefore, this study aims to describe the interactions among digital tools, learning activities, school leadership, teacher collaboration, and stakeholder support during the implementation of digital-based deep learning in primary schools. In doing so, the study offers an empirical contribution by describing how these elements digital tools, pedagogical activities, school leadership, teacher collaboration, and stakeholder support interact within the context of primary schools actively integrating technology. The study does not aim to develop a new conceptual model but rat

This situation presents a relevant context for study at SD Negeri 012 Balikpapan Timur. The school has utilized various digital devices and technologies in its instructional processes, such as digital interactive whiteboards (PID), Chromebooks, and a range of Google for Education-based learning applications. The availability of these digital devices and platforms offers opportunities to foster active student engagement, collaboration, information exploration, and more meaningful learning experiences. Furthermore, SD Negeri 012 Balikpapan Timur is a Google Reference School Candidate (KSRG), a status that encourages the more integrated use of digital technology in learning activities. These conditions make the school a relevant setting for documenting the interplay between digital device usage, instructional practices, school leadership, and teacher collaboration in supporting the implementation of digital-based deep learning. Consequently, this study aims to describe the implementation of digital-based deep learning at SD Negeri 012 Balikpapan Timur and to identify the factors that facilitate or hinder its execution. This study aims to enrich the understanding of implementation practices in the field.

METHOD

This study employs a descriptive qualitative approach to gain an in-depth understanding of the implementation of digital-based deep learning in an elementary school. This approach was selected because it enables the researcher to explore the experiences, practices, and perceptions of educational stakeholders within the natural school setting (Creswell & Creswell, 2023). The study was conducted at SD Negeri 012 Balikpapan Timur, located on Jalan Mulawarman, Batakan Pasar Sore, RT 07, Kelurahan Manggar, Kecamatan Balikpapan Timur, Kota Balikpapan. The school was selected purposively due to its sustained implementation of digital-based learning and its recognition as an institution actively developing digital innovations in instruction. The research took place from April to June 2026. Participants were selected using a purposive sampling technique based on their direct involvement in the implementation of digital-based deep learning. The research informants consisted of one school principal and four teachers who were actively engaged in the planning, execution, and development of digital-based learning at the school. These five informants represent all key actors directly involved in the implementation of digital-based deep learning at SD Negeri 012 Balikpapan Timur; thus, they were deemed capable of providing comprehensive information aligned with the research focus. Data collection was concluded after interviews revealed a repetition of key

themes and no substantive new information regarding the implementation of digital-based deep learning was found. Therefore, the number of participants was deemed sufficient to address the research objectives.

Table 1. Participant Data and Supporting Data Sources

Code	Description	Number
N1	Principal (Interview)	1
N2–N5	Teachers (Interview)	4
O1–O4	Classroom Learning Observations	4
D1	KSRG Program Document	1
D2	Chromebook Usage Schedule	1
D3	Teaching Module	1
D4	Google Classroom/Google Workspace Documentation	1
D5	Teacher Learning Community and Evaluation Meeting Agenda	1
	Total Data Sources	**13**

Data were collected through in-depth interviews, observations, and document analysis. Each informant was interviewed once for a duration of 35–45 minutes. All interviews were conducted in Indonesian, recorded digitally with the informants' consent, and subsequently transcribed verbatim. The interview excerpts presented in the article were translated into English by the researcher. The translation process was carried out independently using Grammarly Translate as an aid, followed by a cross-check against the original Indonesian transcripts to ensure equivalence in meaning, context, and intent for each informant's statement. Given the researcher's background in English Language Education, all translations were independently reviewed before inclusion in the research manuscript to ensure the accuracy and readability of the excerpts. The interview guide focused on the informants' experiences in implementing digital-based deep learning, the development of supporting ecosystems, challenges encountered, and strategies for the sustainability of the school's digital programs. Four observation sessions were conducted involving one lower-grade class and three upper-grade classes focusing on Mathematics and Pendidikan Lingkungan Hidup (PKLH). Each session lasted for 2 × 35 minutes. The observations aimed to document the implementation of digital-based deep learning, specifically regarding the use of digital devices, teacher and student activities, learning interactions, and the characteristics of deep learning encompassing the dimensions of being mindful, meaningful, and joyful. These dimensions were assessed using an observation guide developed based on the deep learning characteristics outlined in the Academic Paper on Deep Learning (Kementerian Pendidikan Dasar dan Menengah, 2025). The guide covered indicators such as students' understanding of learning objectives, active engagement and reflection (mindful); the connection of material to real-life experiences, problem-solving, and the completion of authentic tasks (meaningful); and voluntary participation, curiosity, and positive interaction during the learning process (joyful). Field notes were compiled during and after the observation sessions to systematically document the findings.

Table 2. Observation Guidelines for the Implementation of Digital-Based Deep Learning

Dimension	Observation Indicators
Mindful Learning	The teacher communicates the learning objectives; students understand the learning objectives; students engage consciously in learning activities; students reflect on the learning process or outcomes.
Meaningful Learning	Students connect learning content to their prior knowledge or experiences; students apply concepts in real-life contexts; students solve problems; students complete authentic tasks; students work collaboratively.
Joyful Learning	Students demonstrate curiosity; students participate actively and voluntarily; positive interactions occur among participants; the learning environment is psychologically safe; students show positive engagement throughout the learning process.

Source: Compiled based on Kemdikdasmen (2025)

The observation guidelines served as a reference for identifying the implementation of "deep learning" characteristics during classroom observations. The presence of digital devices was not treated as an indicator of deep learning in itself; instead, these devices were analyzed based on how they supported the realization of the mindful, meaningful, and joyful dimensions of the learning process. Before data collection, the researcher obtained official permission from the Principal of SD Negeri 012 Balikpapan Timur to conduct the study. All informants were briefed on the research objectives, data collection procedures, information confidentiality, and their right to withdraw from the study at any time without consequence before providing voluntary consent (informed consent). Classroom observations were conducted following approval from both the principal and the teaching staff. Students were not involved as research participants or interview informants; their presence was merely part of the observed learning context, and consequently, no data regarding their identities or personal information were collected. All data are presented using participant codes to ensure confidentiality and adhere to research ethics principles.

Document analysis was conducted to complement and verify data obtained from interviews and observations. The documents analyzed included the Educational Unit Curriculum (KSP), the school digitalization program, teaching modules, documentation of learning activities, e-learning schedules, and records of digital platform usage (e.g., Google Classroom). Documents were selected based on their relevance to the research focus and used to gather supporting evidence regarding the implementation of digital-based deep learning. The researcher served as the primary instrument for data collection and analysis, utilizing interview guides, observation sheets, and document review formats designed around the research focus. To minimize interpretation bias, the researcher maintained reflective notes throughout the research process and triangulated data from various sources before establishing final findings. Data analysis employed the interactive analysis model proposed by, comprising data condensation, data display, and conclusion drawing and verification. The analysis process was carried out concurrently with data collection. Interview transcripts, observation notes, and documents were repeatedly reviewed to gain a comprehensive understanding of the data. Subsequently, open coding was performed to identify units of meaning relevant to the research focus. Codes sharing similar meanings were grouped into categories, which were then developed into themes representing the implementation of digital-based deep learning in the school. Final themes were determined through an inductive analysis process, taking into account the interrelationships between categories and the consistency of findings across various data sources.

Table 3. Example of the Research Theme Development Process

Raw Data	Initial Code	Category	Theme
“If we do not keep up with the times, we will be left behind.” (N1)	Adaptation to technological developments	School digital transformation orientation	Needs and Supporting Ecosystem for Digital-Based Deep Learning
“Younger teachers mentor senior teachers. So, there is peer tutoring among teachers.” (N1)	Peer mentoring	Teacher capacity development	Needs and Supporting Ecosystem for Digital-Based Deep Learning
The teacher used a Smart TV to display instructional videos, and students completed assignments through Google Classroom (Observation).	Use of digital media in instruction	Technology integration in the learning process	Implementation of Digital-Based Deep Learning in the Classroom
Students collected plant data in the school environment, documented their findings using Chromebooks, and prepared group presentations (Observation).	Project-based and collaborative learning activities	Active and contextual learning	Implementation of Digital-Based Deep Learning in the Classroom

Source: Author's Interview transcript and observation data, 2026

Table 3 illustrates the theme development process employed in this study. Raw data obtained from interviews, observations, and documents were first identified as initial codes based on the meanings embedded within the data. Codes sharing similar characteristics were then grouped into more conceptual categories before finally being synthesized into the study's main themes. This process was conducted iteratively, involving the comparison of data across sources to ensure the appropriateness and consistency of interpretations. Thus, the research themes were not predetermined based on a specific management framework; rather, they were developed inductively from field data gathered during the research process. Data validity was established through source and technique triangulation. Source triangulation involved comparing information obtained from the school principal and teachers, while technique triangulation entailed comparing results from interviews, observations, and document reviews. The documents utilized included the School Level Curriculum (KSP), the school digitalization program, teaching modules, documentation of learning activities, e-learning schedules, and usage records for digital platforms such as Google Classroom. Research findings were finalized after demonstrating consistency across sources and data collection techniques. Furthermore, any data not fully aligned with the primary patterns of the findings were still considered during the analysis process to verify the accuracy and consistency of the interpretation of the research results.

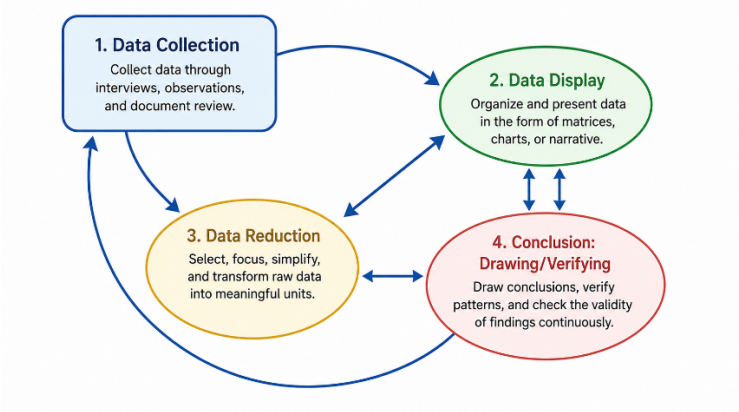

Figure 1. Interactive Model of Qualitative Data Analysis
Source: Adapted from Miles et al. (2014).

RESULTS AND DISCUSSION

Results

Requirements and Supporting Ecosystem for Digital-Based Deep Learning

Interview results indicate that the implementation of digital-based deep learning at SD Negeri 012 Balikpapan Timur stems from the need to align the learning process with technological advancements and the educational demands of the digital era. The principal believes that transforming the learning process is essential to ensure students possess skills relevant to the times and are able to utilize technology positively in their studies. According to the principal during the interview:

"Given the current times, we naturally look at what is required for digitalized learning. Since we are now in the digital age, I must—step by step—shift our learning toward digitalization" (N1).

This need was subsequently integrated into the school's vision, which emphasizes mastery of science and technology to equip students for future challenges. Furthermore, the adoption of technology was driven by the school's desire to optimize existing facilities. As the principal explained:

"If we don't keep pace with the times, we get left behind. We have the equipment, so why not make the most of it?" (N1).

Additionally, the need to implement digital-based deep learning arose from the school's experience with digital devices that had previously been underutilized. One teacher explained:

"At first, we felt like we had Chromebooks but weren't using them. They were only used once a year for the ANBK [National Assessment]. Eventually, we decided: let's put them to use" (N5).

In line with this, other teachers noted that digitalization offers various conveniences for conducting instruction, particularly regarding assessment and the management of learning materials:

"Digitalization makes it easier for us to process and analyze the grades students achieve. It simplifies the tasks of compiling grades and distributing materials beyond standard teaching hours" (N4).

These findings indicate that the need to implement digital learning is driven not only by external demands but also arises from the school's internal need to enhance the effectiveness and quality of instruction.

The successful implementation of digital-based deep learning is also supported by a school ecosystem that encompasses principal leadership, teacher readiness, a collaborative culture, and support from various stakeholders. The principal explained that.

"Younger teachers mentor the senior ones. So, there is peer tutoring among teachers. It turns out to be more effective because they do not feel like they are being lectured by the principal, but rather assisted by their colleagues" (N1).

These efforts are reinforced through Learning Community activities, which serve as a regular platform for sharing best practices and enhancing teacher competence. As another teacher noted:

"To facilitate sharing among teachers, we hold a 'Teacher Learning Day' every Wednesday. That is our forum for sharing, exchanging materials and knowledge" (N5).

Human resource readiness is also reflected in the teachers' ability to utilize various digital devices and platforms to support instruction. These interview findings are corroborated by observations showing that SDN 012 Balikpapan Timur possesses a digital ecosystem that facilitates technology-based learning. The school provides approximately 400–500 Chromebook units for instructional use (O1; D2), a scheduled e-learning room, digital interactive boards (PID) in every classroom, and internet access supported by both the school and parental contributions toward Wi-Fi provision (N1). During observations, teachers were seen utilizing various Google Workspace for Education services such as Google Classroom and Google Drive for both instructional and administrative tasks (O2; D4). Additionally, "Learning Community" (Kombel) activities take place regularly every Wednesday, serving as a platform for teacher professional development (O1; D5). Posters, documentation, and media supporting the digital program were also found throughout the school premises, reinforcing the digital culture. These findings indicate that the school environment supports the integration of technology into learning. However, the mere availability of digital devices and infrastructure does not automatically guarantee the realization of deep learning. In this study, the characteristics of deep learning are identified through activities that demonstrate mindful student engagement, the application of concepts in real-world contexts (meaningful learning), and active, enthusiastic participation (joyful learning), as detailed in the section on classroom implementation. Meanwhile, documents related to the Google Reference School Candidate Program (KSRG), Chromebook usage schedules, and the Teacher Learning Day agenda indicate that teacher capacity building and the utilization of digital devices have been systematically planned as part of strengthening the school's digital ecosystem.

Implementation of Digital-Based Deep Learning in the Classroom

Interview results indicate that the implementation of digital-based deep learning at SD Negeri 012 Balikpapan Timur has been integrated into lesson planning and delivery. The principal explained that the use of digital technology has become part of the instructional process and is incorporated into the teaching materials prepared by the teachers. According to the principal, *"it is explicitly stated in the learning objectives" (N1)*. This implementation is supported by the use of various digital devices available at the school, such as Chromebooks, interactive whiteboards, and

diverse digital learning platforms. The principal emphasized that digital facilities are utilized optimally to support a learning process that aligns with modern developments and the needs of the students. Teachers integrate digital technology into various learning activities that foster active student engagement in the classroom. They utilize digital presentation media, instructional videos, as well as assessment platforms and educational games to create learning experiences that are more engaging and meaningful. As one teacher noted:

"We use slides for the lesson material, but we use forms for assessments. Occasionally, we also use Quizizz and Wordwall for games" (N4).

In a similar vein, another teacher explained that various Google services are utilized to the fullest in the learning process, ranging from Google Classroom, Google Docs, and Google Slides to Google Sheets. According to the interviewee,

"We are required to maximize all Google features, starting with Google Classroom. We upload everything there from learning materials and modules to assignments" (N5).

Another teacher explained:

"Oh, certainly, Ma'am, because the facilities and infrastructure really support the process. Especially with things like digital boards, the children can engage in interactive learning. There are so many interactive learning apps available now like Kahoot, Quizizz, Wordwall, and Bamboozle; basically, there are a great many that we provide to the children." N2

The interview findings were reinforced by observations conducted across four different classes. One observation—carried out during a 6th-grade mathematics lesson on data presentation that utilized the school environment (specifically, plant varieties) as a learning resource—revealed that the teacher began the lesson by stating the learning objectives using a digital interactive board (DIB) and then showed an instructional video to stimulate initial engagement. After the students watched the video, the teacher facilitated a discussion and reinforced the material based on the content viewed. Throughout the lesson, the teacher repeatedly reminded students of the learning objectives and linked them to the activities currently underway. The observations demonstrated instructional practices aligned with the dimension of "mindful learning," evidenced by the clear communication of objectives, reminders of these objectives during the learning process, and teacher-facilitated reflection activities. These findings indicate an effort to help students understand the learning objectives and process more consciously—specifically through the communication of objectives, reminders during the lesson, and end-of-lesson reflection—enabling them to grasp the learning goals, engage consciously in the learning process, and reflect on their learning experiences. In this mathematics lesson on data presentation, students accessed assignments via Google Classroom and worked collaboratively in groups. Each group of six students was divided into two teams: three students were responsible for collecting data on plants within the school grounds using Chromebooks and documenting their observations, while the other three prepared presentation materials in the form of slides.

Observations also showed that students were actively engaged during the learning process. They enthusiastically used Chromebooks to document plant data, engaged in group discussions without constant teacher guidance, and demonstrated curiosity through questions that arose during the data collection process. The classroom atmosphere was interactive, and students voluntarily participated when presenting group work using Google Slides. Based on observations, learning activities demonstrated several indicators related to the joyful learning dimension, such as active student participation, curiosity, and voluntary involvement during group activities. Furthermore, document analysis indicated that digital technology integration was included in the teaching modules used by the teacher. In the mathematics learning module on data presentation, students were directed to collect field data, process the data using digital media, and present the results through Google Slides. These activities demonstrated characteristics of meaningful learning, as students not

only learned the concept of data presentation theoretically but also connected it to real-world situations in the school environment through data collection, processing, and presentation using digital devices. Assignment documents in Google Classroom also indicated that learning activities and assignments were conducted digitally. Overall, the observation results indicate that the implementation of digital-based immersive learning in mathematics learning is not only supported by the use of digital devices but also exhibits characteristics of deep learning. The mindful dimension is reflected through the delivery of learning objectives, conscious student involvement in each stage of the activity, and reflection at the end of the learning process. The meaningful dimension is evident through the use of the school environment as a learning resource, the completion of authentic assignments, and the application of data presentation concepts in real contexts. Meanwhile, the joyful dimension is evident in the enthusiasm, curiosity, collaboration, and active participation of students during the digital-based learning process.

Sustainability Challenges and Strategies

Interview results indicate that the implementation of digital-based deep learning at SD Negeri 012 Balikpapan Timur faces various challenges, both technical and pedagogical. The primary challenge confronting the school is limited supporting infrastructure, particularly regarding the stability of internet connectivity and the power supply. One of the teachers explained that internet connections frequently experience disruptions when digital devices are used simultaneously across multiple classes, and unstable electricity conditions also have the potential to cause damage to digital devices, as noted by one of the teachers:

"In terms of facilities and infrastructure, things are reasonably ready. However, I think there might be an issue with the internet connection; it would be good if that could be improved. Our internet tends to go down sometimes because there are so many users, especially when it's being used simultaneously. Electricity is another issue, too." (N5)

Similar findings were reported by the school principal, who emphasized that the need for internet access continues to rise alongside the increasingly widespread use of technology in instruction:

"Ideally, we want every classroom to have its own permanent interactive whiteboard so that sharing is no longer necessary. We also plan to increase internet capacity, given the growing number of users." (N1)

Beyond technical issues, another challenge concerns the impact of technology use on students' study habits. One teacher commented:

"When children have become too accustomed to digital devices, and we then direct them to go back to writing in notebooks, they complain of fatigue after writing just a little bit. Furthermore, I observe an effect on the children's memory." (N5)

As a sustainability strategy, the school employs an approach that combines digital and conventional learning. The use of Chromebooks and various learning applications is balanced with writing in notebooks and utilizing printed learning resources. This strategy aims to maintain a balance between technological proficiency and the strengthening of students' foundational skills, as explained by another teacher:

"In my own class, even though we actively use Chromebooks, the use of notebooks remains mandatory. This is important for honing their motor skills through handwriting." (N5)

The sustainability of the digital program is also supported through routine monitoring and evaluation. The principal directly monitors classrooms to observe the learning process and identify any emerging challenges. The principal explained this as follows:

"Regarding monitoring, I make rounds every day. I never just stay in the office; I go around and check the classrooms. Then, for evaluation, we hold a coordination meeting once a month." (N1)

The principal further explained:

"I always strive to show appreciation to creative teachers. It isn't always in the form of money, of course, but rather through praise in front of their colleagues or by allowing them to serve as guest speakers at other schools." (N1)

Observations revealed that some digital devices were unavailable for use as they were awaiting repairs (O3). Internet connectivity issues also occasionally caused slow access to digital platforms. Nevertheless, teachers prepared alternative learning methods using textbooks and notebooks to ensure the learning process continued. Observations also indicated the existence of a Chromebook usage schedule, demonstrating that the utilization of digital devices was systematically planned (D2); program implementation was evaluated through monthly coordination meetings (N1; D5), and a specific person was designated to manage the school's digital facilities. These findings indicate that the sustainability of digital-based deep learning implementation at SD Negeri 012 Balikpapan Timur is supported not only by the availability of technology but also by adaptive strategies, continuous evaluation, and the commitment of the entire school community to maintaining the program's continuity.

Discussion

Research results indicate that the implementation of digital-based deep learning at SD Negeri 012 Balikpapan Timur is determined not only by the use of technology in instruction but also by the school's ability to build a digital ecosystem that fosters meaningful, mindful, and enjoyable learning experiences (Prihantoro, 2025). The findings reveal that the utilization of Chromebooks, Google Classroom, Google Workspace for Education, interactive whiteboards, and various digital learning platforms has encouraged active student engagement in the learning process through exploration, collaboration, presentation, and problem-solving activities. This aligns with Rafly et al. (2025), who assert that digital transformation in learning succeeds when teachers are able to integrate technology with effective pedagogical strategies, specifically through the TPACK approach, thereby making learning more interactive and meaningful. In this study, technology serves not merely as a medium for information delivery but as a pedagogical instrument enabling students to construct knowledge through authentic learning experiences (Azimkhan et al., 2025). The successful implementation of digital-based deep learning is further supported by school leadership oriented toward digital transformation (Kustomo, 2025). Research findings indicate that the school principal acts as a driver of change by establishing a shared vision, modeling behavior, empowering teachers, and fostering a collaborative culture. These results reinforce the findings of (Judijanto et al. (2025), which demonstrate that digital leadership significantly influences successful digital implementation through supervision, mentoring, and the development of professional communities.

Furthermore, the existence of Learning Communities (Komunitas Belajar) and Teacher Learning Days serves as a means to enhance teachers' capacity to develop digital-based instruction. These findings align with research by Sanusi et al. (2025) and Siti Nurrofiah et al. (2025), which indicates that learning communities contribute to improving teachers' pedagogical competence through reflection, the sharing of best practices, and the utilization of educational technology. Conversely, this study finds that the sustainability of digital transformation still faces challenges, such as limited internet connectivity, power outages, equipment malfunctions, and the potential for student over-reliance on technology. Nevertheless, the school was able to manage these challenges through a combination of digital and conventional learning, periodic monitoring, and the strengthening of an adaptive learning culture. These findings support the view of Mizova et al. (2026) that the success of digital transformation depends not only on the availability of facilities and infrastructure but also on digital leadership, human resource capacity building, a collaborative culture, and sustainable evaluation systems. Therefore, the successful implementation of digital-based deep learning in this study demonstrates that integrating technology with appropriate

pedagogical strategies can support the development of 21st-century competencies, digital literacy, creativity, and learner autonomy, as highlighted.

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AUTHOR CONTRIBUTION STATEMENT

M contributed to the conceptualization of the study, development of the research focus, investigation, data collection, classroom observation, interview administration, document analysis, data coding, interpretation of findings, and preparation of the original manuscript. ABS contributed to the conceptual development of the study, methodological guidance, supervision, validation of the research process, interpretation of findings, and critical review of the manuscript. S contributed to methodological refinement, validation, supervision, interpretation of the research findings, and review and editing of the manuscript. All authors contributed to the discussion of the findings, critically reviewed the intellectual content of the manuscript, approved the final version for submission, and agreed to be accountable for the integrity and accuracy of the published work.

AI DISCLOSURE STATEMENT

Generative AI tools were used to support manuscript drafting, language refinement, paraphrasing, and academic English improvement, while Grammarly Translate assisted in translating selected interview excerpts from Indonesian into English. All AI-assisted content was reviewed and verified by the authors. AI was not used for data collection, qualitative coding, theme development, or interpretation of the findings. The authors take full responsibility for the accuracy, integrity, and final content of the manuscript.

CONCLUSIONS

This study concludes that the implementation of digital-based deep learning in elementary education depends on the alignment of technological resources, pedagogical practices, teacher capacity, school leadership, and the broader school ecosystem. The findings show that digital technology becomes educationally meaningful when it is integrated purposefully into learning activities rather than used merely as a medium for content delivery. In the observed classrooms, digital tools supported activities reflecting characteristics of mindful, meaningful, and joyful learning through explicit learning objectives, reflection, authentic and contextual tasks, collaborative problem solving, curiosity, and active student participation.

The study contributes to the emerging discussion on digital-based deep learning by demonstrating that its implementation is not primarily determined by the quantity of available technology. Instead, successful implementation emerges from the interaction between digital infrastructure and organizational and pedagogical conditions. School leadership, peer mentoring, teacher learning communities, stakeholder support, and continuous monitoring were found to play important roles in enabling teachers to translate technological resources into pedagogically meaningful practices. This finding reinforces the importance of viewing school digitalization as a systemic educational process rather than simply a technology adoption initiative. From a practical perspective, schools seeking to implement digital-based deep learning should prioritize teacher professional development, collaborative learning among teachers, sustainable infrastructure

management, and the alignment of digital tools with instructional objectives. Schools should also maintain flexible learning strategies that combine digital and conventional approaches to address technical constraints such as internet instability, device maintenance, and electricity disruptions.

The findings should nevertheless be interpreted within the boundaries of the study. The research was conducted in a single elementary school with a limited number of informants and did not directly measure students' cognitive outcomes, learning achievement, or competency development. Therefore, the identified mindful, meaningful, and joyful characteristics represent observed implementation practices rather than evidence of causal improvements in student outcomes. Future research should examine the implementation of digital-based deep learning across diverse school contexts, involve broader participant groups including students, and employ longitudinal or mixed-method designs to investigate how such practices influence learning processes and outcomes over time.

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