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Primary School Teachers' Pedagogical Adaptation to Deep Learning Pedagogy in Digital Classrooms: A Multi-Site Case Study in Ponorogo Regency

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ABSTRACT

Purpose: Of this study is to examine how primary school teachers adapt their pedagogical practices to implement deep learning in digital classrooms, identify forms of adaptation in lesson planning and delivery, and explore the contextual factors that facilitate or hinder this adaptation process. **Methods**: Employed a qualitative multi-site case study design involving eight public elementary schools in Ponorogo Regency, with sixteen teachers and eight principals as informants. Data were collected through interviews, classroom observations, and analysis of instructional documents, and were analyzed thematically following Miles and Huberman's approach combined with Braun and Clarke's thematic analysis. **Findings**: Indicate that teachers' pedagogical adaptation takes three interrelated forms, technical, functional, and pedagogically transformative use of digital technology, that support student interaction, understanding, exploration, problem-solving, and reflection; these forms are shaped by teacher competence, digital infrastructure, school leadership, professional collaboration, professional development, and student characteristics. **Research Implications**: Indicate that digital transformation in primary education requires not only adequate technological infrastructure but also the continuous development of teachers' digital pedagogical competencies, professional collaboration, and opportunities to exercise pedagogical agency. **Originality**: Of this contribution lies in conceptualizing teachers' pedagogical adaptation as the mechanism linking digital classroom transformation with deep learning pedagogy, offering context-specific insights from primary schools in a peripheral regency rather than a broadly generalizable model.

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INTRODUCTION

Advances in digital technology have transformed how schools design, implement, and evaluate learning. The digitalization of education is no longer merely a matter of device availability and internet access; it has driven a shift in how teachers create meaningful learning experiences for students (Taylor et al., 2021). In the context of primary education, this shift is crucial because technology should not be viewed merely as a means of delivering content; instead, it must be utilized to support learning that enables students to grasp concepts deeply, connect knowledge to real-life experiences, reflect on the learning process, and actively engage in problem-solving (Haleem et al., 2022; McCarthy et al., 2023). Consequently, digital transformation necessitates pedagogical changes, not merely technological ones. Research on the digital pedagogical competence of primary school teachers indicates that the ability to use technology effectively is closely linked to a teacher's capacity to integrate technological, pedagogical, and subject-matter knowledge into the learning process (Harahap et al., 2025)

Amidst the evolving landscape of Indonesia's education policy, this need has become increasingly relevant as the approach to deep learning is strengthened. In an educational context, deep learning does not refer to artificial intelligence; rather, it denotes a pedagogical approach that views learning as a conscious, meaningful, and enjoyable experience (Nafi'ah & Faruq, 2025; Zebua, 2025). This approach calls for learning that transcends mere mastery of information, fostering instead conceptual understanding, the connection of knowledge to real-life contexts, reflection, active engagement, and the holistic development of student competencies. The Indonesian government has established deep learning as a key strategy to enhance educational quality, emphasizing the importance of teacher competence in its implementation. The Ministry of Basic and Secondary Education has also identified persisting disparities in

teachers' understanding of deep learning, while positioning teachers as facilitators of learning awareness, initiators of holistic learning, and creators of dignified and enjoyable learning environments (Nurasih & Rochmawati, 2026; Sudirman & Pandang, 2025).

Consequently, the primary challenge in implementing deep learning lies not merely in the availability of digital technology in schools, but in how teachers integrate that technology, along with learning demands into their teaching practices. Teachers must shift their instructional orientation from simply delivering content to facilitating learning experiences that enable students to ask questions, explore, connect concepts, collaborate, solve problems, and reflect (Abao et al., 2023). This process requires teachers to make context-specific pedagogical decisions, as the same technology can yield vastly different learning outcomes depending on how well its use aligns with learning objectives, student characteristics, subject matter, and classroom conditions. Within the TPACK framework, meaningful technology integration occurs when knowledge of technology, pedagogy, and subject matter is not viewed in isolation but is synthesized during instructional decision-making (Fabian et al., 2024). Sakdiah et al. (2024) emphasizes the importance of teachers' digital pedagogical competence in facing the evolution of educational technology.

In the elementary school context, the implementation of deep learning at this level takes place amidst diverse school conditions and varying levels of teacher capacity. Research by Waloyo et al. (2026) which specifically examines the perspectives of primary school teachers in Indonesia, reveals that educators face various obstacles in implementing deep learning, including limitations in capacity and readiness, as well as a need for continuous professional development. Their research further indicates that successful learning reform cannot be achieved solely through policy directives; rather, it requires effective pedagogical strategies alongside active and collaborative teacher engagement. Other studies show that although primary school teachers generally hold positive views regarding deep learning, actual classroom implementation and school readiness remain constrained by various factors, such as time constraints, a lack of instructional materials and technical training, large class sizes, and the need for leadership support and guidance on authentic assessment (Arianti et al., 2025; Fitrah et al., 2025; Jayatri et al., 2025).

Deep learning in Indonesian elementary schools is rapidly developing; however, most existing studies still focus on perception, readiness, competency, or learning approaches in specific subjects. Research conducted by Allolinggi et al. (2025) a study involving 160 elementary school teachers in South Sulawesi examined conceptual understanding, pedagogical and technological readiness, professional development motivation, and perceptions of institutional support related to the implementation of deep learning. Furthermore, the study Musyafa' et al. (2026) The implementation of deep learning in Natural and Social Sciences (IPAS) instruction demonstrates that principles of meaningful and reflective learning can be applied by linking subject matter to real-world issues and employing metacognitive strategies. More recent research also reveals a shift in pedagogical practices toward more learner-centered instruction when deep learning is implemented in primary school classrooms. These findings highlight the strong pedagogical potential of deep learning while underscoring that its success relies heavily on the teacher's ability to translate these principles into concrete instructional practices (Iriawan et al., 2025; Nurihayati & Hanafiah, 2026).

Nevertheless, there remains ample room for further research. Studies on deep learning in primary education tend to focus on teacher readiness, perceptions, or implementation methods, yet they have not sufficiently explored the nuances of teachers' pedagogical adaptations when integrating deep learning with digital technology in daily classroom practice. In reality, teacher adaptation is a far more complex process than mere readiness or competence; teachers must understand policy requirements, select appropriate instructional strategies, tailor technology use to student characteristics, modify classroom interaction patterns, and reflect on the effectiveness of their practices (Adomako Gyasi & Sun, 2026; Bhardwaj et al., 2025). Therefore, focusing on pedagogical adaptation allows research to view teachers not merely as policy implementers, but as active agents negotiating pedagogical changes within their respective school contexts.

This gap is particularly significant in the context of primary schools located in regions with varying levels of technological access and institutional readiness. Preliminary findings from Ponorogo Regency, specifically in the Sawoo, Jetis, and Sambit districts indicate that while some schools possess digital devices and internet access, the use of technology in instruction remains limited to presentations, digital assignment submissions, and rote-based assessments. This situation reflects a disparity between the availability of technology and its actual utilization to foster deep and meaningful learning. Consequently, the presence of technology in the classroom cannot simply be equated with pedagogical transformation. True transformation occurs when teachers successfully integrate technology into instructional designs that support conceptual understanding, active engagement, reflection, and meaningful connections between learning and the students' real-life contexts.

Given this background, the study is crucial because digital transformation in education will not yield improvements in learning quality without a corresponding pedagogical transformation among teachers. This research aims to analyze how primary school teachers adapt their pedagogical practices to implement deep learning in digital

classrooms, identify the forms of adaptation that emerge during lesson planning and implementation, and uncover the contextual factors that facilitate or hinder this adaptation process. The study is expected to make an empirical contribution to the development of research on deep learning and digital pedagogy in primary education, while also serving as a foundation for professional development initiatives that focus not only on technological proficiency but also on the ability to leverage technology to create learning experiences that are mindful, meaningful, and enjoyable.

METHOD

Research Approach and Design

This study employs a qualitative approach with a multi-site case study design to gain an in-depth understanding of teachers' pedagogical adaptation processes during the implementation of deep learning in elementary school digital classrooms (Pahleviannur et al., 2022). A qualitative approach was selected because the research focus was not on quantitatively measuring teachers' readiness or competence, but rather on uncovering the meanings, practices, adaptation strategies, and contextual dynamics that emerge when teachers integrate deep learning and digital technology into their instructional practices. A multi-site case study design was employed to enable an understanding of the phenomenon across multiple school contexts and to allow the researcher to identify adaptation patterns emerging across the schools.

Location and Data Sources

This study was conducted at eight public elementary schools in Ponorogo Regency, distributed across three districts: Sawoo, Sambit, and Jetis. The research sites were selected purposively, taking into account variations in technology access, the characteristics of peripheral areas, and the schools' institutional readiness to implement digital learning. Selection followed three inclusion criteria: (a) the school was a public elementary school located in one of the three districts; (b) at least one interactive digital board or comparable digital device was available for classroom instruction; and (c) the principal agreed to participate and teachers had used digital media in their teaching during the 2025 academic year. Among the schools meeting these criteria, sites were then deliberately varied in terms of internet connectivity, number of available devices, and location (mountainous or peripheral versus more accessible areas), so that the sample would cover a range of institutional readiness rather than only well-resourced schools. The researchers selected eight schools after first observing all the schools in those three districts. These criteria were chosen to ensure contextual diversity, allowing the teachers' pedagogical adaptation process to be understood not merely as an individual matter, but as a process influenced by institutional conditions and the school environment.

The study utilized both primary and secondary data sources. Primary data were obtained from 16 elementary school teachers (key informants) and 8 school principals (supporting informants). Teacher participants were recruited purposively using a maximum-variation logic, with two teachers per school. The inclusion criteria were: (a) being an active classroom or subject teacher at one of the eight schools; (b) having used digital devices or platforms (such as the interactive digital board) in teaching during the current academic year; (c) The teacher's teaching experience has more than five years; and (d) willingness to be interviewed and observed. Within each school, teachers from different grade levels were prioritized so that lower, middle, and upper grades were represented. Each school's principal was included as a supporting informant. Principals provided supporting information regarding policies, institutional conditions, and school support for digital learning implementation. Secondary data included instructional documents, such as lesson plans (RPP), open-access modules, and digital media as well as school policy documents relevant to the implementation of learning activities. This selection of data sources enabled a comparison of perspectives between teachers and school administrators, while also allowing for cross-verification against documentary evidence regarding instructional practices.

Participant characteristics are summarized in Table 1. The sixteen teachers had over ten years of teaching experience; the majority taught at the middle school level, comprising eight general classroom teachers and eight subject-specific teachers (Mathematics, English, and Indonesian). Their experience with digital technology varied: seven teachers had used interactive digital whiteboards for more than three years, seven had just begun using them during the current academic year, and two had undergone formal training in digital learning. The eight school principals had served in their roles for more than five years. This variation was intentional to allow the analysis to examine differences in adaptation based on experience level, grade level, and subject area. The informant codes used in the Results section (T-1 through T-16 and P-1 through P-8) correspond to the participant profiles listed in Table 1.

Table 1. Characteristics of Participants

Characteristic	Category	Amount
Teachers: teaching experience	10 years	8
	10–15 years	4
	> 15 years	2
Teachers: grade level taught	Grades I–II	2
	Grades III–IV	10
	Grades V–VI	4
Teachers: subject taught	Classroom teacher (thematic, multiple subjects)	8
	Subject teacher	8
Teachers: experience with digital technology	Using digital devices in teaching for < 1 year	7
	Using digital devices in teaching for 1–3 years	7
	Has attended formal training on digital learning	2
Principals: tenure and digital experience	Tenure as principal: ≥ 5 years	10
	Tenure as principal: < 5 years	6

Data Collection Techniques and Instruments

Data collection was conducted through in-depth interviews, classroom observations, and document analysis. In-depth interviews were used to explore teachers' interpretations of deep learning, the forms of adaptation strategies implemented, their experiences with digital technology, and the challenges faced in transforming instructional practices. Classroom observations provided direct insight into how deep learning principles and digital interaction technologies were integrated into the learning process. Meanwhile, document analysis focused on instructional materials and media to examine the alignment between lesson planning and actual classroom implementation.

Research instruments, comprising interview guides, observation sheets, and document analysis forms were developed based on the study's focus. The interview guide covered three key aspects: teachers' understanding of deep learning, forms of pedagogical adaptation regarding digital technology use, and factors facilitating or hindering the adaptation process. Observation sheets were used to record actual teaching practices, including lesson design and delivery, teacher-student interaction patterns, technology usage, and indicators of meaningful, reflective, and understanding-oriented learning. Document analysis was performed to compare lesson plans with observed classroom practices. The use of these three instruments enabled data collection regarding teacher adaptation from various perspectives and sources (Sugiyono, 2018).

Research Procedures and Ethical Considerations

Data collection took place between July and August 2026, during the 2026/2027 academic year. Interviews with teachers and principals lasted approximately 45–60 minutes each and were conducted once for most informants, with follow-up interviews held for informants whose responses required clarification. Classroom observations were conducted two to three times per teacher across different lessons to capture variation in practice. To avoid ambiguity between informant categories, teacher informants are coded T-1 to T-16 and principal informants P-1 to P-8 throughout this article, rather than a single shared F-code. Interviews were audio-recorded with the informants' permission and transcribed verbatim, and field notes were written immediately after each classroom observation. Transcripts were coded as described in the data analysis techniques subsection.

Data saturation was assessed based on codes and themes rather than merely on sample size. After the interviews at each school were transcribed and coded, the research team compared the new codes against the existing codebook and used analytical memos to track the number of new codes generated by each additional interview. Saturation was deemed to have been reached when interviews at the final schools yielded no new codes or themes, resulting only in refinements to existing ones and when observations and documents collected at the final sites confirmed previously identified patterns rather than expanding upon them. Given that the number of participants was predetermined in the research design (two teachers per school), the concept of saturation was used to determine whether the data were sufficient for analysis and whether additional participants or interviews were required to address areas where data remained sparse.

This study obtained informed consent from all teacher and principal informants prior to data collection, and consent for the classroom photographs presented in this article was obtained from the respective schools and, where students were identifiable, from their parents or guardians. The research protocol was reviewed and approved by Institute for Research and Community Service at Universitas Muhammadiyah Ponorogo (reference number 601.1/I.1/PN/2026) and research permits were obtained from the Ponorogo District Education Office and the principals of the participating schools. Participants were informed of the study's purpose, the voluntary nature of participation,

and their right to withdraw at any time without consequence, and all data were anonymized using informant codes; school names are not reported in this article.

Researcher Positionality and Reflexivity

The research team consisted of three individuals: the first author a master's student in Pedagogy who conducted all interviews and observations and performed initial coding and two academic supervisors with expertise in education policy and instructional development, who oversaw the study's design, analysis, and interpretation. The first author was neither employed by nor affiliated with the participating schools, and none of the authors held a supervisory or evaluative relationship with the informants. The team acknowledged that their interest in deep learning and digital pedagogy, along with the assumption that teacher adaptation is beneficial, could influence how questions were posed and how data were interpreted. To manage this influence, the researchers (a) maintained a reflective journal throughout the data collection and analysis process to document emerging assumptions, reactions, and interpretations; (b) formulated interview questions neutrally and requested concrete examples rather than evaluative judgments; (c) actively sought out cases that contradicted initial findings such as teachers whose practices remained technical despite favorable conditions; and (d) discussed interpretations during regular sessions among the authors, where the supervisors reviewed and re-examined the first author's interpretation of the data.

Data Validity

Data validity is ensured through source triangulation and method triangulation. Source triangulation involves comparing information obtained from teachers, the school principal, and instructional documents. Meanwhile, method triangulation entails comparing findings from interviews, classroom observations, and document analysis. These procedures serve to verify the consistency of the information and reduce reliance on a single data source when describing the teachers' instructional adaptation process.

Data Analysis Techniques

Data analysis was conducted thematically by integrating a qualitative analysis model Huberman & Miles (2012) as well as Braun and Clarke's thematic analysis approach (Ahmed et al., 2025). The process begins with the reduction and organization of data obtained from interviews, observations, and documentation, followed by coding to identify units of meaning related to teachers' pedagogical adaptation. Interrelated codes are grouped into categories and themes, then presented in matrices or narratives to reveal patterns emerging at each research site. The final stage involves drawing and verifying conclusions by comparing patterns across sites and cross-verifying findings against interview, observation, and documentary data. This analytical procedure enables the study to identify patterns of teacher adaptation and the contextual factors influencing the implementation of deep learning within a digital ecosystem. Table 2 shows how the two approaches were combined operationally.

Table 2. Operational Integration of Miles and Huberman's Model and Braun and Clarke's Thematic Analysis

Stage	Miles and Huberman	Braun and Clarke	Operational procedure
1. Preparation	Data condensation	Phase 1: Familiarization	Verbatim transcription; repeated reading of transcripts, observation notes, and documents; initial analytic memo for each school.
2. Initial coding	Data condensation	Phase 2: Generating initial codes	Manual, line-by-line inductive coding of interviews, observations, and documents using one shared codebook (code name, definition, illustrative excerpt).
3. Category development	Data condensation and within-case display	Phase 3 (part): Collating codes	Codes with related meanings grouped into categories; within-case matrix for each school (categories × informants and data sources).
4. Theme generation	Within-case display	Phase 3–4: Searching for and reviewing themes	Categories clustered into candidate themes; themes checked against coded extracts and the full data set, then merged, split, or discarded.
5. Cross-case analysis	Cross-case display	Phase 4–5: Reviewing, defining, and naming themes	Cross-case matrix (schools × themes) to identify shared patterns and differences related to device availability, connectivity, and leadership; themes refined and named.
6. Verification and reporting	Conclusion drawing and verification	Phase 6: Producing the report	Triangulation of interview, observation, and document data; checking of negative cases; selection of extracts; writing of findings.

Initial coding and category development. The first author read the interview transcripts, observation notes, and instructional documents repeatedly and coded them manually, line by line, using an inductive approach so that codes stayed close to informants' words and observed practices (for example, "teacher uses the digital board to invite student questions"). The theoretical framework (deep learning pedagogy, TPACK, and teacher agency) was not used to impose codes at this stage; it served as an interpretive lens during theme review. Each code was recorded in a codebook with a definition and an illustrative excerpt, and the codebook was revised as new codes emerged. Codes with related meanings were then grouped into categories, and a within-case matrix was built for each school, displaying the categories against informants (teacher and principal) and data sources (interview, observation, and document).

Theme generation and cross-case analysis. Categories were clustered into candidate themes, which were checked against the coded extracts and the entire data set and were merged, split, or discarded until each theme was internally coherent and distinct from the others. The within-case matrices were then compared in a cross-case matrix (schools × themes) to identify patterns shared across schools and differences associated with site conditions such as device availability, connectivity, and leadership support. Themes were refined and named at this stage, producing the three main themes reported in the Results. As an illustration, the codes "the interactive board is used for students to solve problems," "the teacher asks questions during the demonstration," and "feedback on students' solution steps" were grouped into the category "technology as learning interaction." Together with the category "teacher as facilitator," it formed part of the theme "adaptation of teachers' pedagogical practices," and cross-case comparison of such patterns informed the identification of the three forms of adaptation (technical, functional, and pedagogical-transformative).

Resolving interpretive differences. To mitigate the risks associated with single-coder interpretation, the second and third authors independently coded all interview transcripts and observation notes using the draft codebook. Discrepancies in interpretation were noted, discussed during analysis meetings, and resolved by cross-referencing transcripts, field notes, and documents until consensus was reached; if consensus could not be achieved, the academic supervisor made the final decision following discussion. After each meeting, the codebook was revised, definitions were clarified, and the remaining data were re-coded in accordance with these changes. Since reflexive thematic analysis does not assume the existence of a single "correct" coding, the aim of this process was to enrich and test interpretations and ensure consistency, rather than to calculate inter-coder reliability coefficients. Analytic memos and various versions of the codebook were retained as an audit trail.

In the final stage of conclusion drawing and verification, conclusions were drawn by comparing patterns across sites and were cross-verified against interview, observation, and documentary data, with attention to negative cases. This analytical procedure enables the study to identify patterns of teacher adaptation and the contextual factors influencing the implementation of deep learning within a digital ecosystem.

Subsequent data interpretation employs a framework encompassing deep learning pedagogy, TPACK, teacher professional adaptation theory, and teacher agency. The deep learning perspective is used to examine characteristics of meaningful, reflective, and understanding-oriented learning; TPACK is utilized to analyze the interaction among technological, pedagogical, and content knowledge in teaching practice; while the perspectives of professional adaptation and teacher agency are applied to understand how teachers interpret, respond to, and adjust to pedagogical changes and the demands of digital learning. Through this framework, the analysis moves beyond merely identifying technology usage; it aims to explain how technology is pedagogically adapted to support deep learning and to identify the factors shaping this adaptation process.

RESULTS

Analysis of data obtained through interviews, classroom observations, and document studies across eight elementary schools reveals that teachers' pedagogical adaptations during the implementation of deep learning in the classroom occur gradually. This adaptation is evident not only in teachers' proficiency with digital tools but, more importantly, in how technology is integrated with pedagogical strategies, learning materials, student characteristics, and learning objectives. The research findings encompass three key themes: (1) the adaptation of teachers' pedagogical practices in digital learning, (2) the forms of adaptation during the lesson planning and implementation stages, and (3) the contextual factors that facilitate or hinder teacher adaptation.

Adaptation of Teachers' Pedagogical Practices in the Implementation of Deep Learning

Research findings indicate that the use of digital technology in the schools studied spans a diverse spectrum. Initially, technology was primarily utilized as a means to deliver instructional materials and manage administrative tasks. Teachers employed digital devices to display content, assign tasks, or convey information to students. Indeed, early findings revealed that technology use in some schools was still dominated by presentation media, assignment submissions via WhatsApp, and assessments focused on rote memorization. However, observations also showed the

emergence of practices shifting toward the integration of technology into the students' learning experience. For instance, in mathematics lessons, interactive digital whiteboards served not merely as screens for displaying material but also as spaces for interaction between teachers and students as they worked to grasp the concepts being studied.

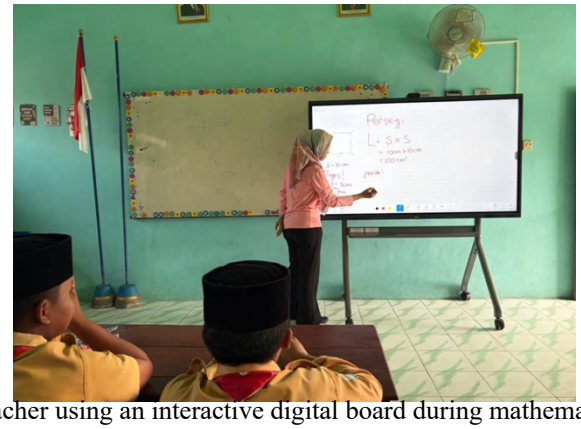

Figure 1. A teacher using an interactive digital board during mathematics instruction.

In this situation, students not only receive teacher explanations but are also given the opportunity to interact directly with the material presented and solve the problems presented. This pattern indicates a shift from technology as a presentation tool to technology as a learning interaction. This finding is also evident in the changing role of the teacher during learning. The teacher is no longer solely the center of information delivery, but has begun to act as a facilitator who asks questions, guides students in experimenting, and provides feedback on the problem-solving process. One teacher (T-1) explained that,

> *"I currently act as a facilitator for the classroom learning process, guiding and providing direction whenever adjustments are needed. Students are given the freedom to direct their own activities; for instance, in a mathematics lesson on 3D shapes, they are presented with a real-world example, such as a building displayed on an interactive digital board. They then logically explain how to calculate its surface area, rather than simply memorizing formulas."*

The statement indicates that teacher adaptation involves not only the ability to operate digital devices but also the capacity to modify how those devices are used to align with learning objectives. Teachers at other schools (T-2, T-3) echoed this sentiment, noting that the presence of interactive digital boards effectively compelled them to improve; they were required to keep pace with advancements in the educational landscape and adapt to the characteristics of the current generation of students. Findings from the analysis of instructional documentation, specifically teaching modules reinforce this pattern; digital technology was included not merely as a presentation tool but as an integral component of every face-to-face session. Thus, within the context of this study, pedagogical adaptation can be understood as a process wherein teachers integrate technology, pedagogy, and subject matter to create more active and meaningful learning experiences. These findings are consistent with the TPACK framework. This suggests that changes in practice are shaped not solely by technological proficiency, but also by the teacher's ability to blend technology with pedagogical strategies and the specific characteristics of the subject matter; this typology is treated as an empirically derived pattern across cases rather than a confirmed developmental sequence, and its theoretical implications are examined further in the Discussion.

Forms of Adaptation in Lesson Planning and Implementation

Teacher adaptation is also evident in the planning and implementation stages of learning. During the planning stage, teachers adjust media, activities, and learning strategies by considering the characteristics of the subject matter and student abilities. This adaptation is reflected in teachers' efforts to select materials that can be visualized using digital technology and design activities that provide opportunities for students to observe and experiment, ask questions, and solve problems. A teacher interview (T-4) explained,

> *"Before the lesson begins, I select appropriate materials to display digitally on the interactive whiteboard. I prepare everything to prompt activities and questions from the students, ensuring they remain active rather than passive."*

During the implementation phase, adaptation is evident in teachers' flexibility in changing strategies based on student responses. Teachers do not strictly adhere to the lesson plan, but make adjustments when students experience difficulties or respond differently than expected. Interviews with teachers (T-5) explained that,

> *"I will first provide a more detailed explanation based on the plan I have prepared, which outlines the use of interactive media and online websites to facilitate student understanding; once I have gathered everything, I will display it on the digital board, elaborating with explanations and real-life examples."*

The emerging pattern indicates that instructional adaptation is not merely a matter of the technology employed, but also of how teachers make decisions during the learning process. Teachers act as agents who actively interpret classroom situations and adjust strategies based on learners' needs. This demonstrates the nature of teacher agency in the implementation of deep learning.



Figure 2. Teacher providing guidance and feedback to students.

In addition to learning strategies, adaptation is also evident in assessment patterns. Teachers pay attention to students' process of understanding and solving problems, not just the final answer. An interview with a teacher (T-6) explained,

> *"After adopting a more active learning approach using this interactive whiteboard, I am better able to assess the students' learning process, as I can visualize the material, which I previously prepared as images or posters in a more tangible way. Students can also follow the steps to solve a problem and connect the subject matter to the experiences or simulations I present."*

The findings indicate that the implementation of deep learning drives simultaneous adaptations across several instructional components: activity planning, media usage, classroom interaction, feedback provision, and assessment. Therefore, pedagogical change cannot be understood solely through the presence of digital tools, but rather through the transformation of how teachers design and manage learning experiences.

Table 3. Forms of Teachers' Pedagogical Adaptation in Digital Classrooms.

Learning Stage	Initial Practice	Forms of Adaptation	Learning Orientation
Planning	Materials and tasks prepared using conventional methods	Materials and activities adapted for digital technology	Understanding and engagement
Delivery of material	The teacher does most of the explaining	Technology is used for visualization and stimulation	Conceptual understanding
Interaction	One-way communication	Question and answer, demonstrations, and digital interaction	Active participation
Activities	Regular exercises and assignments	Exploration and problem solving	Meaningful learning
Assessment	Focused on final answers	Attending to process and understanding	Reflection and understanding

Based on this pattern, teachers' pedagogical adaptations can be categorized into three forms: technical adaptation, functional adaptation, and pedagogical-transformative adaptation. Technical adaptation occurs when technology is primarily used to assist in the delivery of course material. Functional adaptation emerges when technology begins to be used to enhance student activities and interactions. Finally, pedagogical-transformative adaptation occurs when

technology is integrated with instructional strategies that foster understanding, problem-solving, reflection, and active student engagement.

Contextual Factors Facilitating and Hindering Teacher Adaptation

Cross-site analysis shows that teachers' pedagogical adaptation processes are influenced not only by individual abilities but also by the conditions of the school ecosystem. The identified factors can act as both supporting and inhibiting factors in this adaptation process. The first supporting factor is the availability of digital devices and infrastructure. Schools with adequate digital devices and internet access provide teachers with more space to experiment with various learning strategies. However, the mere presence of infrastructure does not automatically result in in-depth learning. Initial research findings indicate that even when schools are equipped with devices and internet connectivity, their implementation tends to be limited to presentations, communication assignments, and assessments that rely on memorization. The second factor is principal support and school culture. Institutional support creates space for teachers to experiment and develop new learning practices. An interview with the principal (P-1) explained,

> *"As the principal, I will provide teachers with the opportunity to use digital tools and experiment with new teaching strategies, while also offering support whenever they encounter difficulties using interactive digital boards."*

Similar sentiments were expressed by all the principals selected for the study. However, two principals (P-2, P-3) added that they would seek collaboration with universities, both in Ponorogo Regency and outside the city, that have teaching faculties to support their teachers in strengthening digital learning. A third factor is teacher professional development. Teachers who have the opportunity to learn and discuss the use of technology and in-depth learning tend to be better able to develop a variety of learning practices. Teacher (T-7) explained,

> *"I participate in training and mentoring sessions organized by the Education Office, as well as online programs conducted by the Ministry; these have been immensely helpful in enabling me to use the applications effectively and gain a deep understanding of the material, ensuring that the students at my school truly grasp both the technology and the subject matter."*

Furthermore, researchers also found several inhibiting factors, namely limited digital learning competency, limited time, network constraints due to the school's location in a mountainous area, device availability, and learning habits that are still oriented towards delivering material and completing assignments on student worksheets. Interviews with teachers (T-8) include:

> *"The lack of organized training and limited networking opportunities at our school have constrained our capabilities; while teachers are genuinely supportive of collaboration, current efforts fall short of meeting the demands of today's rapidly evolving landscape."*

Echoing this sentiment, the teacher (T-7) elaborated on the challenges faced:

> *"Since there is only one device, setting it up takes a long time; it has to be moved from one classroom to another, so we sometimes end up using it collectively for general themes."*

The findings indicate that teachers' adaptation of their teaching practices is a process influenced by the interplay between individual and institutional factors. Teachers may possess the willingness to make changes, yet limitations regarding equipment, connectivity, time, school support, or professional development opportunities can constrain the scope of their adaptation.

Table 4. Factors Supporting and Hindering Pedagogical Adaptation

Factors	Enabling	Inhibiting
Teacher competence	Willingness to learn and experience using technology	Limitations of digital learning
Infrastructure	Digital devices and internet access	Network disruptions and device limitations
Leadership	Principal support	Support is uneven
Professional development	Training and mentoring	Training is more technically oriented
School culture	Collaboration among teachers	Conventional teaching habits
Learners	Response and enthusiasm regarding technology	Differences in ability and digital literacy

Overall, the findings indicate that teachers' pedagogical adaptation occurs within an ecosystem rather than as an individual process. This research framework conceptualizes the digital education ecosystem as the interconnection among various educational stakeholders, technology, policies, and school culture. Thus, the successful implementation of deep learning is determined not only by a teacher's ability to operate technology but also by the school ecosystem's capacity to create conditions that enable teachers to enact pedagogical changes.

DISCUSSION

Research findings indicate that teachers' pedagogical adaptation during the implementation of deep learning in digital classrooms does not occur automatically simply due to the availability of technology. Adaptation takes place when teachers align the use of technology with learning objectives, the characteristics of the subject matter, and the needs of the learners. Initially, technology is often used merely to present materials, assign tasks, and conduct assessments; however, in more advanced practice, it is utilized to foster interaction, provide stimuli, visualize concepts, and support problem-solving (Noura, 2024; Timotheou et al., 2022). These findings indicate that the digitalization of learning is not synonymous with pedagogical transformation, as technology can actually reinforce traditional practices if not accompanied by changes in learning strategies.

These findings can be explained through the Technological Pedagogical Content Knowledge (TPACK) framework, which views technology integration as the intersection of technological, pedagogical, and content knowledge (Elkosi & Widayati, 2025). For instance, the use of interactive digital whiteboards across all research sites holds greater pedagogical value when they serve not merely to display content but also to engage students in interaction, experimentation, answering questions, and problem-solving. Thus, a teacher's adaptation is determined not by the sheer number of devices or applications employed, but rather by their ability to define the technology's pedagogical function. This perspective highlights the need for teachers to evolve beyond possessing mere technical skills to becoming capable of effectively integrating technology with instructional strategies and learning objectives (Mahardhani, 2023; Ningsih & Herwanis, 2024).

Adaptation is also clearly evident during the lesson planning and implementation stages. Teachers adjust media, activities, strategies, and feedback methods based on the nature of the material and student responses. When students encounter difficulties, teachers modify explanations, provide additional examples, or alter learning activities. This demonstrates teacher agency, the capacity of teachers to interpret the demands for change and make pedagogical decisions suited to actual classroom conditions (Surata, 2026; Toropova et al., 2021). In this context, teachers are not merely implementers of digitalization policies but active agents who determine how technology is translated into meaningful learning practices.

Viewed from the perspective of deep learning, this adaptation marks a shift from instruction oriented toward information delivery to a learning experience that provides space for students to understand, explore, solve problems, interact, and reflect (Nafi'ah & Faruq, 2025). Research findings indicate that teacher adaptation is observed in three interrelated forms technical, functional, and pedagogical-transformative adaptation, each associated with a deeper understanding and a richer learning experience; because the design is cross-sectional, these forms are treated as a typology of adaptation identified across cases rather than a confirmed developmental sequence. This typology suggests that the success of digitalization should be measured by improvements in the quality of learning, rather than merely by the frequency of technology usage (Nurasih & Rochmawati, 2026).

Contextual factors also play a crucial role in this process. Factors such as device availability, internet access, principal support, a collaborative culture, professional development, and student characteristics can either facilitate or hinder teachers' adaptation efforts (Kucirkova et al., 2026; Mohzana et al., 2024). Preliminary findings indicate that although technology is available, its use in some schools remains limited to presentations, assignment submissions via whatsapp, and assessments based solely on rote memorization. This suggests that pedagogical adaptation is ecological in nature (Indah et al., 2024), as it depends on each teacher's ability to navigate institutional conditions and the school environment. School support is crucial in creating space for teachers to experiment, collaborate, and engage in continuous professional development.

Overall, this study demonstrates that teachers' pedagogical adaptation serves as the link between classroom digitalization and the implementation of deep learning. The TPACK framework explains how teachers integrate technology, pedagogy, and subject matter; the concept of teacher agency explains how teachers make decisions and adjustments; and school ecosystem factors explain the conditions that either facilitate or hinder this process. Therefore, the digital transformation of schools cannot rely solely on the procurement of devices and the enhancement of teachers' technical skills; it must also encompass the development of digital pedagogical capacity, ongoing mentoring, professional collaboration, and school leadership that fosters innovation. Consequently, the success of digital transformation should be measured by the extent to which technology helps teachers create learning experiences that

are meaningful, active, reflective, and focused on student understanding, rather than merely by the volume of technology used.

This study has several limitations. Because it draws on eight purposively selected schools within three districts of Ponorogo Regency, its findings are context-specific rather than statistically generalizable, and transferability to other regions should be judged by readers based on contextual similarity. Not all schools exhibited the pedagogical-transformative form of adaptation to the same degree; a small number of teachers, particularly those with limited access to devices, described their practice as remaining largely technical despite institutional support, suggesting that individual and infrastructural constraints can offset otherwise favorable school conditions. Future research employing longitudinal designs across a broader range of school contexts would help clarify whether teachers move between the identified forms of adaptation over time and would strengthen the transferability of these findings.

CONCLUSION

This study concludes that teachers' pedagogical adaptation is a key factor in linking classroom digitalization with the implementation of deep learning in primary schools. Teacher adaptation is demonstrated not only by the ability to use digital devices but also by the capacity to integrate technology with pedagogical strategies, learning materials, and student needs, thereby leveraging technology to enhance interaction, exploration, problem-solving, understanding, and reflection. The study identifies three interrelated forms of adaptation, technical, functional, and pedagogical-transformative rather than a confirmed developmental sequence, given the cross-sectional nature of the design; in the pedagogical-transformative form, technology becomes an integral component of deep learning design. This process highlights the importance of TPACK (Technological Pedagogical Content Knowledge) in integrating technology, pedagogy, and content, as well as the role of teacher agency in making adjustments based on real-world learning conditions. At the same time, teacher adaptation does not occur in isolation; it is shaped by the school ecosystem, including the availability of devices and network infrastructure, principal support, a culture of collaboration, professional development opportunities, and student characteristics. Therefore, the success of digital transformation in primary schools cannot be measured solely by the availability or intensity of technology use, but rather by the extent to which teachers can transform technology into a means of fostering meaningful, active, and reflective learning centered on student understanding. As the findings are drawn from eight purposively selected schools in three districts of Ponorogo Regency, they should be understood as context-specific insights that may transfer to similarly resourced peripheral settings rather than as population-level generalizations; longitudinal studies are needed to examine whether teachers actually progress between the identified forms of adaptation over time, and comparative studies across rural, urban, and differently resourced school ecosystems would further test the transferability of these findings. The study suggests a need for school digitalization policies that go beyond mere infrastructure procurement and technical training, focusing instead on strengthening teachers' digital pedagogical capacity, providing ongoing mentoring and professional collaboration, and fostering school leadership that creates space for instructional innovation.

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AUTHOR CONTRIBUTION STATEMENT

IS: Conceptualization, methodology, data collection, data analysis, and initial draft preparation. AR: Supervision, conceptualization, methodology, interpretation of findings, and manuscript review and editing. SU: Supervision, methodology, interpretation of findings, and manuscript review and editing.

AI DISCLOSURE STATEMENT

The authors used ChatGPT (OpenAI) during the preparation of this manuscript to refine language and structure, as well as to enhance the clarity and coherence of the academic writing. ChatGPT was not used to generate, fabricate, or manipulate research data, including data derived from interviews, observations, documentation, or research findings. All empirical data were obtained directly by the authors through the research process, and the authors bear full responsibility for the accuracy, authenticity, analysis, interpretation, and presentation of the research findings. Following the use of the AI tool, the authors thoroughly reviewed, verified, and edited the generated content and assume full responsibility for the final content of this publication.

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