

Exploring the Digital Paradox of Deeper Mathematical Learning: A Phenomenological Study of Indonesian Mathematics Teachers

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Received: September 5, 2026

Accepted: October 26, 2026

Online Published: October 28, 2026

doi:10.11114/jets.v15i1.9280

URL: <https://doi.org/10.11114/jets.v15i1.9280>

Abstract

Digital technology can make mathematics more visual, interactive, and exploratory, yet it does not necessarily lead to richer mathematical activity. This study explores how Indonesian mathematics teachers experience digital technology and make sense of its potential for deeper mathematical learning. Guided by Moustakas's transcendental phenomenology, the study included 67 mathematics teachers, with 24 purposively selected for in-depth interviews and analysis of digital learning artefacts. The study analyzed data phenomenologically and compared sources, using NVivo 12 Pro to organize the data. The findings show that teachers valued technology for explaining concepts, visualizing abstract ideas, and engaging students, while facing challenges related to digital skills, student readiness, and classroom conditions. Teachers made sense of technology through five overlapping purposes: presentation, explanation, visualization, interaction, and exploration. However, analysis of 67 artefacts showed that presentation-oriented uses were more common than simulation-based activities. This tension defines the Digital Paradox: the possibilities teachers recognize do not always match the mathematical learning opportunities represented in their instructional designs. The findings highlight the importance of understanding not only how teachers experience and interpret technology, but also how its possibilities are reflected in the learning activities they design.

Keywords: digital technology, phenomenology study, digital paradox, deeper mathematics learning

1. Introduction

Digital technology has expanded the possibilities for learning mathematics. Concepts previously represented through symbols, static images, or teacher demonstrations can now be visualized, manipulated, simulated, and explored through interconnected representations (Koskinen & Pitkäniemi, 2022; Wijaya et al., 2022). Students can change parameters, observe changes, test hypotheses, and explore mathematical relationships directly (Aldaleel, 2025; Zhan et al., 2024). These capabilities position digital technology not merely as a medium for conveying information, but as an environment that can enrich how students interact with mathematics (Mabalane Jr., 2025). This potential aligns with the demands of deeper mathematics learning, which encompasses conceptual understanding, connections between representations, exploration, and reasoning. Empirical evidence shows that technology can support deep learning when it enriches students' engagement with learning content and processes (Huang et al., 2024; Orhani, 2024).

However, the growing range of technological possibilities does not automatically lead to a more in-depth mathematics learning experience. Technology that supports visualization, manipulation, simulation, and exploration can still be used to present material, provide explanations, offer practice exercises, or check answers (Drijvers & Sinclair, 2024; Zhang, Wang, et al., 2025). Research also shows that technology use in mathematics learning spans a broad spectrum, from presentation and practice to activities that allow student exploration and engagement (Kim et al., 2023; Sungur Gül & Ateş, 2023). The issue is no longer simply whether technology offers affordances for deeper learning, but rather how these possibilities translate into mathematical activities that students experience (Beswick et al., 2023). Expanding technological affordances does not always expand

mathematical enactment (Engelbrecht & Borba, 2024). This tension forms the starting point for the “Digital Paradox” in this study: technology may offer more possibilities, but not all translate into richer mathematical experiences.

Teachers play a crucial role in addressing this tension because technology does not automatically carry didactic meaning (Nopriana et al., 2023). Teachers interpret learning objectives, the material's characteristics, students' needs, and the actions technology can facilitate before deciding how to use it. Technology can clarify concepts and representations, but it can also create space for exploration, hypothesis testing, making connections between representations, and mathematical reasoning (Mogaji et al., 2024). Previous research has extensively examined technology adoption, acceptance, digital competence, integration, and Technological Pedagogical Content Knowledge (Li, 2025). These studies describe various capacities and conditions that support technology use. However, they do not fully explain how teachers interpret technology's possibilities or how they translate those interpretations into mathematical activities (Ma et al., 2025). Knowing which technologies teachers use alone does not explain whether those technologies function as tools for presenting mathematics or as spaces for performing, exploring, and reasoning about mathematics. This gap positions “teacher interpretation and enactment” as a crucial layer between technological affordances and mathematical activity.

The Indonesian context provides a relevant empirical setting for examining this process. Mathematics teachers use a variety of digital technologies, including dynamic mathematics software, artificial intelligence, instructional videos, digital quizzes, online learning platforms, and spreadsheets (Setiyani et al., 2022; Siswanto et al., 2025). However, this diversity of technologies does not yet explain how teachers determine the didactic meaning of the available options or how they realize those options in mathematics activities. This study uses a phenomenological approach to understand teachers' experiences and interpretations and analyzes digital learning artifacts to examine how these interpretations manifest in practice. Converging these two data sources enables this study to uncover the gap between what teachers perceive as technological possibilities and what they ultimately realize in mathematics activities (Cahyono et al., 2023; Kurniawan et al., 2026). This study does not view technology use or digital competencies as the primary indicators of learning transformation. Instead, this study shows that teachers' interpretation and enactment determine whether technological affordances develop into deeper mathematical activities or remain limited to presentation and learning-support functions. This study's main contribution is an empirical explanation of the Digital Paradox as the tension between the expansion of technological possibilities and the limitations of mathematical enactment. Thus, technology that can do more does not necessarily enable students to do more mathematically. This study explores Indonesian mathematics teachers' experiences using digital technology and how they interpret its possibilities and limitations for deeper mathematics learning. This study addresses two questions: (1) How do Indonesian mathematics teachers experience the use of digital technology in mathematics learning? Moreover, (2) How do Indonesian mathematics teachers make sense of the possibilities of digital technology for deeper mathematical learning?

2. Conceptualizing the Digital Paradox in Mathematics Learning

2.1 Digital Technology as a Source of Mathematical Possibilities

Digital technology in mathematics education not only conveys information but also opens new possibilities for students to interact with mathematical objects and concepts. Dynamic visualizations, manipulations, simulations, multiple representations, and feedback allow students to change conditions, observe changes, compare representations, explore patterns, and test conjectures more directly (Khatin-Zadeh et al., 2025; Shishigu et al., 2026; Zhang, Zhang, et al., 2025). These possibilities are understood through the perspective of didactic affordance—that is, the action potential that arises from the relationship between the characteristics of the technology, the user, and the learning activity (Kong & Wang, 2024). This perspective shifts the focus from questions about the technology's features to questions about the mathematical activities it can enable. The didactic value of a technological possibility is not inherent in the technology itself. The ability to manipulate objects, for example, can be used merely to demonstrate changes predetermined by the teacher or to enable students to explore relationships, discover patterns, and test hypotheses. The same technology can open different possibilities for activities when placed within different learning objectives, tasks, interactions, and decisions (Luo, 2023; Sacristán, 2024). These differences indicate that technological possibilities are initial conditions, not guarantees of deeper mathematical learning. The key conceptual issue is how these possibilities are understood and selected for implementation in mathematical activities.

2.2 From Technological Possibilities to Deeper Mathematical Activity

Deeper mathematics learning is characterized by students' engagement in activities that go beyond applying procedures and arriving at answers. These activities include connecting representations, recognizing patterns and relationships, exploring changes, testing conjectures, providing justifications, constructing arguments, and applying understanding to different situations (Saleem et al., 2022). Digital technology can support these activities through dynamic visualization, manipulation, simulation, multiple representations, exploration, and feedback (Fajriah et al., 2025; Setiyani et al., 2022). The role of technology in mathematics learning should therefore be evaluated not by the number of features or its level of sophistication. However, it should be evaluated by the types of mathematical activities it makes possible. The

relationship between technology and deep learning is indirect. Technology's possibilities must first be translated into learning activities that give students a mathematical reason to use them (Ngiruwonsanga et al., 2026; Yilmaz et al., 2023). For example, technology that provides dynamic simulations has transformational value only when students use it to observe relationships, compare cases, test conjectures, or construct explanations (Wang et al., 2025). Using technology to display information or provide exercises still serves a learning function, but it does not, in and of itself, expand the types of mathematical activities students engage in. This distinction is a crucial basis for differentiating the “digitalization of teaching” from the “transformation of mathematical activity”.

2.3 Teachers as the Interpretive Layer

Teachers play a crucial role in navigating the possibilities technology and mathematical activities offer. Teachers not only decide whether to use technology, but also interpret which possibilities are relevant, select those that align with learning objectives, and translate them into learning tasks and interactions. Teachers’ understanding of mathematics, learning objectives, students’ needs, classroom readiness, time, facilities, and experience using technology shape this process (Andrews et al., 2023; Löfström et al., 2026). The didactic meaning of technology is therefore shaped through sense-making, not merely by the technology’s inherent characteristics. The teacher’s role as an “interpretive layer” explains why the same technology can lead to different mathematics practices. GeoGebra, for example, can be interpreted as a tool for clarifying visual representations, but it can also be positioned as an environment for manipulating objects, exploring relationships, and testing hypotheses. This difference lies less in the technology’s capabilities than in how teachers interpret and choose from the available possibilities (Bento Miguens et al., 2024). This perspective complements studies on Technological Pedagogical Content Knowledge and teacher design capacity, which extensively address teachers’ knowledge and ability to integrate technology (Cevikbas & Kaiser, 2022; Fitriana et al., 2025). This study shifts the emphasis by positioning teachers’ interpretations as the layer that determines how technological possibilities acquire didactic meaning before being realized in mathematical activities.

2.4 The Digital Paradox as an Affordance–Enactment Tension

Based on this relationship, this study views the Digital Paradox not merely as a situation in which advanced technology fails to produce deep learning. More specifically, the Digital Paradox refers to the tension between the ever-expanding range of technologically available possibilities and their limitations when realized as mathematical activities in learning practice (Singh et al., 2024; Wimelius et al., 2021). This tension arises through teachers’ interpretation and selection processes. Technology can provide visualization, manipulation, simulation, multiple representations, exploration, and interaction, but only a portion of these possibilities is ultimately realized in learning activities (Ciriello et al., 2019).

This study’s conceptual framework posits that teachers first understand technological possibilities through sense-making. This sense-making then influences didactic selection—the process by which teachers determine which technological possibilities are relevant to learning objectives, content characteristics, student needs, and classroom conditions (Bruner & Haste, 2010). These choices then shape how teachers enact technology and which mathematical activities students can engage in. Thus, the relationship between technology and mathematics learning is not direct; it unfolds through teachers’ interpretive processes and didactic decisions.

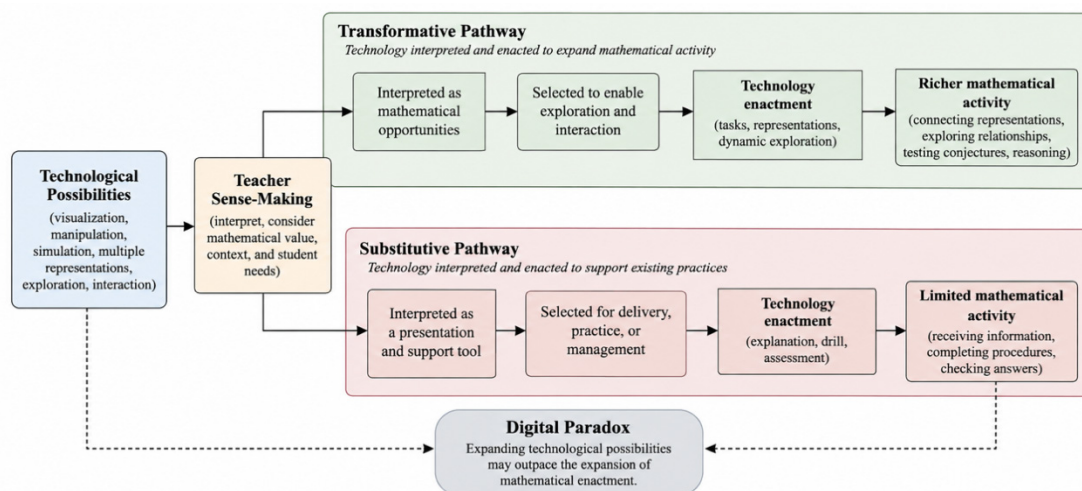


Figure 1. Conceptual model of the Digital Paradox: From technological possibilities to mathematical enactment

The model includes two conceptual pathways. In the transformative pathway, teachers interpret technology's potential through its mathematical value; they select it to open opportunities for exploration and interaction, then implement it through activities

that encourage students to connect representations, explore relationships, test conjectures, and reason (Yang & Kaiser, 2022). In the substitutive pathway, teachers interpret technology's potential primarily in terms of its benefits for presentation, explanation, practice, or learning management, so technology replaces or reinforces existing practices without significantly expanding students' mathematical activities. Both pathways can occur with the same technology because the difference lies not solely in the technology's capabilities but in how teachers give meaning to and realize that potential.

This conceptual framework clarifies the Digital Paradox in this research. The paradox does not lie in technology's failure to provide rich learning possibilities. The paradox lies in the fact that technological possibilities can expand more rapidly than mathematical enactment (Grigore et al., 2021). The more possibilities that are available, the more important the teacher's interpretive processes and didactic decisions become in determining which possibilities become part of mathematical activities. This perspective underpins phenomenological research—not merely to ask what technologies teachers use, but to understand how teachers experience, interpret, select, and realize the possibilities of technology in mathematics learning.

3. Method

3.1 Research Design

This study adopted a phenomenological research design informed by Moustakas's (Moustakas, 1994) transcendental phenomenology to understand how Indonesian mathematics teachers experience and make sense of digital technology in their teaching. Rather than examining how frequently teachers use technology or their levels of digital competence, the study focused on how they interpret its potential and incorporate it into mathematics learning activities. This approach provided a basis for examining the meanings teachers attached to their experiences within their teaching contexts (Neubauer et al., 2019). The analysis sought to identify significant statements, develop textural and structural descriptions of teachers' experiences, and synthesize their shared meanings to capture the essence of the Digital Paradox. This paradox reflects the tension between the pedagogical possibilities of digital technology and the extent to which these possibilities are realized in ways that support deeper mathematical thinking (Ciriello et al., 2019).

3.2 Participants and Context

The broader study involved 67 mathematics teachers, from whom 24 were purposively selected for the phenomenological phase. These teachers participated in in-depth interviews and provided digital learning artifacts related to their mathematics teaching. Selection was based on their direct experience using digital technology in mathematics instruction and their ability to describe how they interpreted its potential and incorporated it into teaching activities. The study also considered variation in participants' backgrounds, including gender, age, educational background, teaching experience, school level, geographical region, and experience with digital technology. This variation provided a broader range of experiences through which to examine how teachers made sense of digital technology in different teaching contexts. Table 1 summarizes the characteristics of the 24 participants.

Table 1. Characteristics of Teachers Participating in the Phenomenological Phase

Category	Subcategory	n	%
Gender	Male	8	33.3
	Female	16	66.7
Age (years)	25–30	7	29.2
	31–40	8	33.3
	41–50	6	25.0
	>50	3	12.5
	Bachelor's degree (S1)	15	62.5
Educational Background	Master's degree (S2)	9	37.5
	1–5	7	29.2
Teaching Experience (years)	6–10	6	25.0
	11–15	5	20.8
	16–25	6	25.0
School Level	Primary	5	20.8
	Junior Secondary	10	41.7
	Senior Secondary	9	37.5
Region	Java	13	54.2
	Sumatra	4	16.7
	Kalimantan	3	12.5
	Sulawesi	4	16.7
	1–3	5	20.8
Digital Technology Experience (years)	4–6	8	33.3
	7–10	7	29.2
	>10	4	16.7

The study received ethical approval from the relevant institution before data collection. All participants were informed

about the study's objectives and procedures and voluntarily provided informed consent. Participants' identities were protected throughout data analysis and reporting. Interview recordings, transcripts, and digital learning artifacts were handled confidentially to safeguard participants' privacy.

3.3 Data Collection

Data were collected through in-depth, semi-structured interviews and digital learning artifacts. The interviews served as the primary source for uncovering teachers' lived experiences and how they made sense of digital technology. The interview protocol included 18 main questions designed to address the study's research focus and conceptualization of the Digital Paradox, particularly the relationship between teachers' interpretations of digital technology and its enactment in mathematics learning activities. Questions focused on teachers' concrete experiences using technology, how they recognized its potential, what they considered when choosing how to use it, and how they realized that potential in mathematics learning activities. For example, the interviews explored how teachers understood digital technology's potential for mathematics learning, what informed their decisions to use digital tools, and how their intended uses appeared in classroom activities. Each interview lasted approximately 120 minutes and included 18 main questions, with follow-up questions used to probe participants' experiences and reflections. We recorded all interviews with participants' consent and transcribed them verbatim.

Digital learning artifacts provided contextual evidence of how teachers' interpretations of technology manifested in practice. The artifacts included digital teaching materials, worksheets, presentations, GeoGebra activities, instructional videos, digital quizzes, screenshots, and other forms of digital media used in mathematics instruction. The artifacts were not treated as standalone indicators of technology quality; instead, they were analyzed alongside the interview narratives to understand how teachers' interpretations related to the enactment of technology in mathematical activities. Comparing interview accounts with these artifacts helped examine how teachers stated intentions aligned with the learning activities represented in their digital materials.

3.4 Data Analysis

The analysis followed these iterative stages: data familiarization, phenomenological reduction, identification of significant statements through horizontalization, development of meaning units, construction of textural and structural descriptions, and synthesis of the essence of the phenomenon. NVivo 12 Pro was used to organize, code, search, and compare interview transcripts and learning artifacts. The software supported data management and retrieval, while the researchers remained responsible for interpreting participants' experiences.

The analysis began with repeated readings of the transcripts to identify meaning units related to experiences, interpretations, decisions, and technology enactment (Moustakas, 1994). Significant statements were examined in relation to the phenomenon under study, with attention to how teachers experienced and interpreted the possibilities of digital technology in mathematics learning. Related meaning units were then compared and organized into broader categories and themes that captured both shared experiences and differences across participants. Interview accounts were examined alongside digital learning artifacts to explore how teachers' interpretations were reflected in their instructional practices. The emerging themes were compared across participants and data sources to identify patterns, variations, and tensions between the technological possibilities teachers perceived and the mathematical activities they implemented in practice. These findings informed the development of textural descriptions of what teachers experienced and structural descriptions of how those experiences were shaped by their teaching contexts. The analysis was then synthesized to formulate the essence of the phenomenon—that is, the fundamental meaning of how teachers experience and interpret the possibilities of digital technology in deeper mathematics learning.

3.5 Trustworthiness

The findings' validity is supported by credibility, dependability, confirmability, and transferability. Credibility was strengthened through in-depth interviews and comparison of teachers' narratives with digital learning artifacts to examine how their interpretations related to the instructional practices represented in those artifacts. Dependability was supported through systematic documentation of the data collection process, transcription, the development of meaning units and themes, and analytical decision-making. Confirmability was strengthened by maintaining traceability between significant statements, meaning units, themes, and the resulting interpretations, alongside reflective notes during analysis. Transferability was supported by describing the research context, participant characteristics, and types of digital learning artifacts examined, allowing readers to assess the relevance of the findings to similar mathematics teaching contexts.

4. Results

4.1 Overview of the Analytic Findings

An analysis of in-depth interviews and digital learning artifacts shows that teachers' experiences relate not only to technology use but also to how they interpret and realize technology's potential in mathematics learning activities. The interviews reveal teachers' interpretations and considerations, while the artifacts show how they put those interpretations into practice.

Examining both sources together helps identify connections and differences between the possibilities teachers recognize and the mathematical activities represented in their learning materials. Comparing the two data sources reveals an interpretive gap between the possibilities of technology teachers recognize and the mathematical activities ultimately implemented. Technology viewed as having the potential to support exploration and reasoning is not always used for those purposes. These findings provide an empirical basis for understanding the Digital Paradox—a condition in which expanding technological possibilities is not always accompanied by an expansion of students' mathematical activities. Table 2 presents the analytical pathway from both data sources to the phenomenological findings.

Table 2. Analytic Pathway from Data Sources to Empirical Findings

Analytic Component	Data Source	Analytical Focus	Empirical Output
Experiential accounts	In-depth teacher interviews	Teachers' experiences, interpretations, purposes, and perceived technological possibilities	Teachers' meanings of digital technology in mathematics learning
Enacted practices	Digital learning artefacts	Forms of technology use and mathematical activities embedded in learning materials and tasks	Evidence of how technological possibilities are enacted
Cross-source comparison	Interviews and digital learning artefacts	Convergence and divergence between teachers' accounts and enacted practices	Patterns of alignment and interpretive gaps
Thematic synthesis	Both sources	Recurring meanings, practices, and tensions across participants	Two interconnected dimensions: teacher meaning-making and technological enactment
Synthesis of the essence	Both sources	Shared meanings across teachers' experiences and the relationship between their interpretations and enacted practices	An understanding of how teachers' interpretation and enactment of digital technology shape its contribution to deeper mathematics learning

Taken together, the findings are presented in three connected stages. Section 4.3 examines teachers lived experiences with digital technology, including the opportunities and constraints they encountered. Section 4.4 explores how teachers interpreted technology's potential in relation to their didactic purposes and mathematics learning activities. Section 4.5 brings these findings together to examine the gap between the possibilities teachers recognized and those reflected in the learning activities represented by the digital artefacts. This synthesis provides the basis for understanding the Digital Paradox in the context of teachers' experiences and practices.

4.2 Digital Technology Enactment Revealed through Learning Artefacts

An analysis of 67 digital learning artifacts revealed nine patterns of technology enactment, ranging from presentation-oriented uses to combinations of presentation, assessment, games, and simulations. These patterns were identified based on the functions of digital tools and the mathematical activities represented in the learning materials. Figure 2 presents the distribution of these patterns.

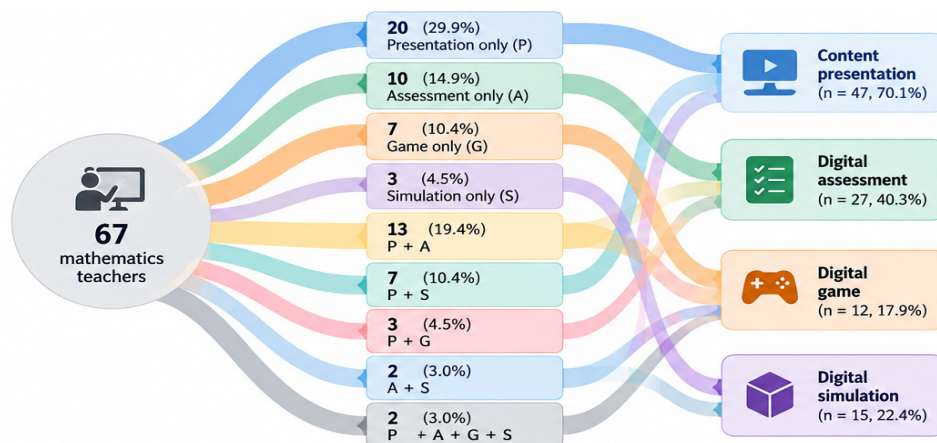


Figure 2. Patterns of Digital Technology Enactment in Mathematics Learning

Figure 2 shows that presentation-oriented use was prominent, whereas simulation-based use appeared in both standalone and combined forms. This pattern suggests that the availability of diverse digital tools does not necessarily lead to equally diverse mathematical activities. The key issue is not simply which technologies teachers use, but whether the activities they design enable students to investigate mathematical relationships, manipulate representations, and develop reasoning. The artifact analysis therefore provides a basis for examining the Digital Paradox and raises a further question: how do teachers interpret technological possibilities and decide which of them to incorporate into mathematics learning?

4.3 Teachers' Lived Experiences with Digital Technology

Analysis of the teachers' responses revealed five interconnected dimensions of experience: understanding, engagement, exploration, adaptation, and contextual constraints. Together, these dimensions illustrate how teachers experienced digital technology as a potential resource for mathematics teaching while negotiating the practical demands of classroom implementation. Table 3 presents representative statements and their phenomenological interpretations.

Table 3. Experiential Patterns in Teachers' Use of Digital Technology

Experiential dimension	Illustrative quotation	Brief phenomenological interpretation
Understanding	"GeoGebra can be used to explain something that I previously considered complicated." (R08)	Technology was experienced as making difficult mathematical ideas easier to represent and explain.
Engagement	"At first, the students were confused and struggled to use it, but once they understood how to use it, they became more enthusiastic and asked to use technology more often." (R03)	Engagement emerged through students' growing familiarity with the technology rather than occurring automatically upon its introduction.
Exploration	"I was curious and found it interesting that a mathematical concept could be digitized with the help of technology." (R56)	Teachers perceived opportunities to present mathematical concepts through digital representations, although this did not necessarily mean that students independently explored mathematical relationships.
Adaptation	"I felt quite challenged because I had previously used lecture-based or conventional methods. I needed time to learn how to use Quizizz." (R03)	Adopting technology was experienced as a process of learning, overcoming uncertainty, and adjusting established teaching practices.
Contextual constraints	"Digital technology is very useful in teaching, but I sometimes face limitations because of the available facilities and infrastructure, as well as my limited knowledge of digital technology." (R50)	Teachers' experiences were shaped by the interaction between perceived technological benefits and the resources and skills available to them.

Table 3 illustrates that teachers' experiences extended beyond whether digital technology was considered useful or interesting. They experienced its value in teaching situations: explaining concepts they found difficult, responding to students' enthusiasm, considering new forms of mathematical representation, and learning to use unfamiliar tools. At the same time, their experiences were shaped by practical conditions, including available facilities and their own technological knowledge.

These patterns indicate that teachers' experiences of digital technology were neither uniformly positive nor determined solely by the tools' features. Instead, teachers' perceived value of technology emerged from their efforts to connect its possibilities to mathematical content, students' responses, and classroom conditions. The following section examines how teachers interpret the pedagogical role of digital technology in mathematics learning.

4.4 How Teachers Make Sense of Digital Technology for Mathematics Learning

Teachers' accounts suggest that the meaning of digital technology is shaped more by its mathematical and instructional purposes than by the technology's type or sophistication. Their responses indicate that technology may be valued for presenting content, clarifying explanations, visualizing abstract ideas, facilitating interaction, or enabling mathematical exploration. We interpreted these meanings by considering teachers stated purposes alongside the functions represented in their digital learning artefacts. The five categories are not stages of teacher development or a hierarchy of technological competence. Instead, they describe different, potentially overlapping ways in which teachers understand the didactic possibilities of technology.

Table 4. Teachers' Didactical Meanings of Digital Technology in Mathematics Learning

Didactical meaning	Illustrative teacher statement	Evidence from learning artefacts	Interpretive meaning
Presentation	"Technology helps teachers deliver material in a simple way that students can understand." (R03)	E-books, PowerPoint, Canva, and other digital presentation materials were prominent in the artefact analysis.	Technology was valued as a means of organizing and delivering mathematical content, often retaining the teacher's role as the primary source of explanation.
Explanation	"Technology is not a replacement for the teacher, but it can help explain mathematical concepts in a more visual, interesting, and understandable way." (R04)	Digital teaching materials and instructional videos provided resources for explaining mathematical content.	Technology was understood as a resource for clarifying concepts and supporting students' access to explanations.
Visualization	"Illustrations of geometric figures and abstract concepts, such as algebra, can help students imagine the concepts." (R56)	GeoGebra activities and other visual resources represented mathematical objects and concepts.	Technology was valued for making mathematical objects and relationships more visible, particularly when they were difficult to imagine or represent statically.
Interaction	"My goal in using digital technology is to present learning materials, provide interactive questions, manage student assignments, and increase students' motivation and involvement." (R03)	Digital quizzes and assessment tools, including Quizizz and Google Forms, appeared in the artefacts.	Technology was understood as a means of eliciting student responses and supporting participation, although interaction with a digital interface does not necessarily entail mathematical reasoning.
Exploration	"In some situations, simulation of figures, such as plane and solid shapes, can be more effective when using technology." (R56)	A smaller proportion of artefacts involved digital simulations that could support the manipulation and investigation of mathematical representations.	Technology was perceived as offering opportunities to investigate mathematical relationships. Whether these opportunities supported student-led exploration depended on how the activities were designed.

The comparison between teachers' accounts and digital learning artefacts reveals that the meaning teachers assign to technology does not always correspond directly to how it is enacted in practice. Although teachers recognize its potential to support richer mathematical experiences, the artefacts show that these possibilities are not consistently translated into activities that require students to investigate mathematical relationships or develop their own reasoning. This distinction highlights the importance of examining not only what teachers believe technology can offer, but also how those possibilities are incorporated into learning activities.

These findings suggest that the didactic value of digital technology depends on how teachers interpret and enact its possibilities in relation to mathematical learning objectives and classroom conditions. The following section examines the alignment and divergence between teachers' interpretations and the practices represented in their artefacts, providing a basis for understanding the Digital Paradox.

4.5 The Digital Paradox: An Interpretive–Enactment Gap

The cross-source analysis revealed a tension between the possibilities teachers associated with digital technology and the forms of use documented in their learning artefacts. Teachers described technology as a resource for clarifying mathematical concepts, visualizing abstract ideas, and engaging students. However, the artefact analysis showed that content presentation and digital assessment were more prominent than simulation-based activities. This contrast provides evidence of an interpretive–enactment gap, although the extent of the gap must be considered in relation to what each data source can establish.

Table 5. Cross-Source Synthesis of the Digital Paradox

Analytic dimension	Empirical evidence	Interpretive significance
Perceived technological possibilities	Teachers described technology as useful for visualizing abstract concepts, clarifying explanations, and engaging students.	Teachers recognized multiple pedagogical possibilities beyond the delivery of information.
Didactical intentions and decisions	Teachers' responses referred to instructional purposes, student engagement, and the practical demands of using digital tools.	Teachers interpreted technological possibilities in relation to their perceived teaching needs.
Documented enactment	The 67 artefacts included presentation materials, digital assessments, games, and simulations, with presentation-oriented uses appearing most frequently.	The documented uses reflected a selective realization of the possibilities associated with digital technology.
Relationship between interpretation and enactment	Teachers' accounts emphasized several potential benefits, whereas the overall artefact distribution showed fewer simulation-based activities.	The two sources suggest a divergence between the breadth of perceived possibilities and the forms of use represented in the artefacts.
Phenomenological synthesis	The accounts and artefacts together revealed both the perceived value of technology and the limits of what was documented in instructional materials.	The Digital Paradox concerns the relationship between teachers' interpretations of technology and the mathematical opportunities represented in their learning designs.

The comparison highlights an important distinction between recognizing a technological possibility and incorporating it into a learning activity. For example, teachers identified visualization as a way to make abstract mathematical ideas more accessible, while the artefact analysis showed that presentation materials were more common than simulation-based activities. This is a pattern across the dataset rather than proof that a particular teacher failed to enact an intention. Establishing such a connection at the individual level would require matching a teacher's interview account with that teacher's corresponding artefact.

The findings therefore suggest that the Digital Paradox is not simply a matter of whether teachers use digital technology. It concerns how the possibilities they recognize are represented in the learning activities they prepare. The artefacts provide evidence of documented instructional designs, but they do not necessarily capture every interaction or teaching decision that occurred in the classroom.

Taken together, the findings point to a shared meaning across teachers' accounts and the artefacts: the educational significance of digital technology depends not only on the possibilities it offers, but also on how teachers interpret those possibilities in relation to mathematical purposes and classroom conditions. The Digital Paradox thus emerges as a tension between the range of possibilities teachers recognize and the range of mathematical opportunities visible in the analysed learning materials. This interpretation shifts attention from technology adoption alone to the relationship between teachers' lived experiences, didactical meaning-making, and the mathematical activities their designs make available to students.

5. Discussion

This study examined how Indonesian mathematics teachers experience using digital technology in mathematics learning and how they make sense of its potential to deepen mathematical learning. By considering teachers' accounts alongside digital learning artefacts, the findings offer insight into both teachers' lived experiences and the ways they interpret the pedagogical possibilities of technology. The discussion addresses these two dimensions in turn before bringing them together through the concept of the Digital Paradox.

Regarding the first research question, the findings show that teachers' experiences of digital technology involve both perceived opportunities and practical challenges. Teachers described technology as helpful for explaining abstract concepts, visualizing mathematical ideas, and engaging students (Latifi & Kasumi, 2022). At the same time, they reported challenges associated with learning unfamiliar tools and responding to classroom conditions, including students' readiness and the availability of facilities and infrastructure. These experiences complement previous studies examining technology integration in relation to teachers' digital competencies, readiness, perceived benefits, TPACK, and design skills (Cahyono et al., 2023; Kurniawan et al., 2026; Wijaya et al., 2022). These findings add a phenomenological perspective by showing how teachers experience the perceived value of technology in relation to teaching circumstances. Teachers' experiences were not uniformly positive, nor were they determined by technological features alone. Instead, they reflected the interaction among perceived pedagogical value, teachers' familiarity with digital tools, students' responses, and the conditions of instruction. This interpretation is consistent with research emphasizing the importance of resources and contextual conditions in technology integration (Dalle et al., 2024).

Regarding the second research question, the findings show that teachers make sense of digital technology through the didactical purposes they associate with its use. The analysis identified five overlapping categories: presentation, explanation, visualization, interaction, and exploration. These categories reflect different ways teachers understand technology's potential contribution, rather than a hierarchy of technological competence or a fixed progression toward deeper learning. For example, a teacher may value a digital tool because it makes a mathematical idea more visible, supports an explanation, or provides opportunities for student participation (Roman Shkilev et al., 2024). The significance of each possibility depends on the mathematical content, instructional purpose, and classroom circumstances in which the tool is used. This interpretation complements research on teacher design capacity and digital resource design, which emphasizes recognizing technological affordances and making informed instructional decisions (Cevikbas & Kaiser, 2022; Fitriana et al., 2025). It also extends discussions of technology integration beyond competence-based explanations (Khodabandelou et al., 2026). The ability to operate a digital tool does not, by itself, establish how its features will be used to support mathematical thinking. Teachers must interpret the relationship between technological possibilities, mathematical objectives, students' needs, and classroom conditions. Teacher sense-making therefore offers an interpretive perspective on how technological possibilities acquire didactical meaning, without assuming a fixed sequence or independence from contextual constraints.

Comparing teachers' accounts with digital learning artefacts further clarifies the relationship between these two research questions. Teachers' accounts revealed a range of possibilities they associated with technology, while the analysis of 67 artefacts showed that presentation-oriented uses were more prominent than simulation-based activities. This contrast provides an empirical basis for interpreting the Digital Paradox as an interpretive–enactment gap: the possibilities teachers recognize are not always fully represented in the instructional designs documented by the artefacts. This finding supports

the broader observation that digital technology does not automatically produce deeper learning (Priawasana, 2024) by highlighting how teachers' interpretations relate to the forms of technology use visible in their learning materials. However, the pattern must be interpreted at the dataset level. It does not establish that teachers failed to realize their stated intentions, nor does it demonstrate that activities not represented in the artefacts never occurred during classroom instruction. Instead, the comparison reveals a tension between the breadth of possibilities described in teachers' accounts and the forms of use represented in the collected materials.

This interpretive–enactment gap also helps clarify the relationship between technological affordances and mathematical activity. Digital tools can offer dynamic representations and opportunities for interaction or investigation (Gil-Doménech & Berbegal-Mirabent, 2020; Polman et al., 2021). Nevertheless, the availability of these features does not necessarily mean that the tasks designed around them invite students to investigate mathematical relationships, connect representations, or develop their own reasoning (Ellis et al., 2022). The findings therefore suggest that the educational significance of digital technology depends partly on how teachers relate its possibilities to mathematical purposes and instructional conditions. Technological sophistication and mathematical sophistication should not be treated as equivalent. This study does not establish a causal mechanism explaining why certain forms of technology use occur; instead, it offers a phenomenologically informed interpretation of the tension between teachers' perceived possibilities and the mathematical opportunities visible in their instructional materials. Analyzing artefacts alongside teachers' accounts makes this relationship more visible, while recognizing that artefacts document aspects of instructional design rather than the entirety of classroom experience.

These findings have implications for teacher professional development. Training that focuses exclusively on operating digital tools or increasing technology use may not fully address the interpretive decisions involved in mathematics teaching (Davis & Granić, 2024). Professional learning could instead help teachers examine how specific technological features relate to mathematical objectives, compare alternative task designs, and consider whether learning activities give students opportunities to explore relationships, connect representations, test conjectures, and justify their reasoning (Cirneanu & Moldoveanu, 2024). Such work should also acknowledge practical constraints, including preparation time, available facilities, students' readiness, and teachers' confidence in using unfamiliar tools. The aim is not to privilege exploration over presentation or assessment in every situation, but to help teachers make deliberate choices about the mathematical purposes that technology is intended to serve.

Taken together, the findings position the Digital Paradox as a synthesis of teachers' experiences, their didactical sense-making, and the forms of technology use represented in their learning artefacts. Its significance lies in the tension between the possibilities teachers associate with digital technology and the mathematical learning opportunities visible in their documented instructional designs. This interpretation shifts the discussion of digital transformation beyond technology adoption alone. It highlights the importance of understanding not only what teachers experience when using digital technology, but also how they interpret its possibilities in relation to deeper mathematical learning. Future research could examine this relationship by more closely analyzing matched teacher accounts, instructional artefacts, and classroom interactions to more precisely establish how teachers' interpretations are reflected in enacted teaching practices.

6. Conclusion

This study explored how Indonesian mathematics teachers experience using digital technology in mathematics learning and how they make sense of its potential to deepen mathematical learning. Regarding the first research question, the findings show that teachers' experiences are shaped by the opportunities and challenges they encounter in practice. Teachers described digital technology to clarify mathematical concepts, visualize abstract ideas, and engage students. However, their experiences were also influenced by students' readiness, teachers' familiarity with digital tools, and the availability of supporting facilities and infrastructure. These findings highlight that teachers' experiences with digital technology are shaped by the practical conditions of mathematics teaching.

Regarding the second research question, the findings show that teachers make sense of digital technology through different didactical purposes, including presentation, explanation, visualization, interaction, and exploration. These meanings reflect how teachers interpret technology's potential in relation to mathematical content, instructional objectives, and classroom needs. However, the analysis of 67 digital learning artefacts showed that presentation-oriented uses were more prominent than simulation-based activities. This pattern suggests that the range of possibilities teachers recognize does not always correspond to the forms of use visible in their documented learning materials. However, the artefacts do not necessarily capture every interaction or instructional decision in classroom practice.

Taken together, these findings inform the concept of the Digital Paradox as a tension between the possibilities teachers associate with digital technology and the mathematical learning opportunities represented in their instructional designs. The study suggests that digital technology's contribution to deeper mathematical learning cannot be understood solely in terms of adoption or technical sophistication. Instead, attention must be given to how teachers interpret and incorporate

technological possibilities into activities that encourage students to explore mathematical relationships, connect representations, and develop reasoning. This perspective offers implications for teacher professional development and future research by emphasizing the relationship between teachers' lived experiences, didactical sense-making, and the design of meaningful mathematical learning activities.

Acknowledgments

The authors gratefully acknowledge financial support from Direktorat Penelitian dan Pengabdian kepada Masyarakat, Direktorat Jenderal Riset dan Pengembangan, Kementerian Pendidikan Tinggi, Sains, dan Teknologi Republik Indonesia, through the BIMA Research Funding Program 2026. The authors also thank all participants and supporting parties for their valuable contributions to this study.

Author contributions

BA led the conceptualization and design of the study, coordinated data collection, led the data analysis, and prepared the initial manuscript draft. AN contributed to the research design, methodological review, and refinement of the data collection instruments. RG contributed to data collection, data review, and interpretation of the findings. WW contributed to the analysis of digital learning artefacts, data organization, and verification of the alignment between the data and the findings. IS contributed to the interpretation of the findings and critical revision of the manuscript. LM contributed to the review of the research content, critical revision of the manuscript, and refinement of the final version. All authors reviewed and approved the final version of the manuscript.

Funding

This research was supported by the Direktorat Penelitian dan Pengabdian kepada Masyarakat, Direktorat Jenderal Riset dan Pengembangan, Kementerian Pendidikan Tinggi, Sains, dan Teknologi Republik Indonesia, through the BIMA Research Funding Program 2026.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Redfame Publishing.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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Appendix A

Table A1. Alignment of the Interview Protocol with the Research Questions

Research focus	Conceptual foundation in the study	Interview question	Purpose of the question
RQ1: Teachers' lived experiences	Moustakas's (1994) transcendental phenomenology; teachers' lived experiences	1. Can you describe your experience when you first encountered a new digital technology for teaching mathematics?	To elicit a concrete account of teachers' experiences.
RQ1: Initial perceptions	Teachers' experiences and interpretations of digital technology	2. What first came to mind when this technology was introduced?	To explore teachers' initial perceptions and responses.
RQ1: Meaning of experience	Phenomenological exploration of the meanings attached to experience	3. What led you to view the technology in that way?	To explore the experiences or considerations underlying teachers' perceptions.
RQ1: Responses to change	Teachers' experiences within their teaching contexts	4. How do you usually respond to new developments or innovations in education? Can you describe a particularly memorable experience?	To understand how teachers experience and respond to change.
RQ1 and RQ2: Decision-making	Teachers' interpretations of technological possibilities and contextual conditions	5. What considerations usually arise before you decide to try a new technology?	To identify factors shaping teachers' decisions.
RQ1 and RQ2: Influences on decisions	Teachers' experiences and the contexts shaping technology use	6. Who or what experiences have most influenced your decision to try new technology?	To explore the influences informing teachers' decisions.
RQ2: Meaning of digital technology	Teachers' interpretations of the pedagogical possibilities of technology	7. What does digital technology mean for the professional role of mathematics teachers today?	To explore the meanings teachers attach to technology in mathematics education.
RQ2: Interpretation and use	Relationship between teachers' interpretations and technological enactment	8. How do your views about technology influence your decisions to use or not use it in mathematics teaching?	To examine how teachers' views relate to their instructional decisions.
RQ2: Didactical purposes	Technological possibilities in relation to mathematical teaching and learning	9. What purposes do you use digital technology for in your mathematics teaching?	To identify the instructional purposes teachers associate with technology.