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Digital literacy, low-code pedagogical ecosystems, and innovative teaching in primary education

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Abstract
Background: Digital transformation in elementary schools continues to advance alongside the increasing use of technology in learning. However, the presence of technology has not always been accompanied by the emergence of innovative teaching practices, as the mechanisms explaining the relationship between teachers' digital literacy, the technological environment, and pedagogical competence are not yet fully understood.
Purpose: This study aims to analyze the relationship between digital literacy, a low-code-based pedagogical ecosystem via microsites, Technological Pedagogical Content Knowledge (TPACK), and innovative teaching practices among elementary school teachers.
Method: This study employed a quantitative explanatory survey involving 83 elementary school teachers in Jepara Regency, Indonesia, selected through proportional stratified random sampling. Data were collected using a structured questionnaire measuring digital literacy, low-code pedagogical ecosystems, TPACK, and innovative teaching practices. Structural Equation Modeling–Partial Least Squares (SEM-PLS) was employed to examine the direct and indirect relationships among the proposed constructs.
Findings: The findings reveal that digital literacy strongly promotes the use of low-code pedagogical ecosystems, which subsequently strengthen teachers' TPACK competencies. TPACK emerged as the primary mechanism underlying innovative teaching practices, with significant indirect effects observed for Digital Literacy → TPACK → Innovative Teaching Practice ($\beta = 0.231$, $p = 0.001$), Low-Code Pedagogical Ecosystem → TPACK → Innovative Teaching Practice ($\beta = 0.266$, $p < 0.001$), and the sequential pathway Digital Literacy → Low-Code Pedagogical Ecosystem → TPACK → Innovative Teaching Practice ($\beta = 0.167$, $p = 0.001$). The proposed model explained 67.8% of the variance in innovative teaching practices ($R^2 = 0.678$). Moreover, Digital Literacy demonstrated a large effect on the Low-Code Pedagogical Ecosystem ($f^2 = 0.649$), while TPACK exerted the strongest effect on innovative teaching practices ($f^2 = 0.702$), confirming its central role in digital pedagogical transformation.
Keyword: digital literacy; low-code pedagogical ecosystem; microsite; innovative teaching practices; primary education;.

INTRODUCTION

Digital transformation has become one of the most influential trends in contemporary education (Cortellazzo et al., 2019; Fernández et al., 2023; McCarthy et al., 2023). In many countries, the integration of technology is no longer viewed as a mere supplement to the learning process but rather as an integral part of the educational ecosystem that shapes how teachers teach and students learn (Nurhayati et al., 2025; Quliyeva, 2023; T. Taufikin, Badawi, et al., 2025). Educational institutions adapt to the increasingly rapid pace of social change. Advances in artificial intelligence, digital learning platforms, cloud computing, and data-driven technologies have expanded the learning environment beyond the boundaries of conventional classrooms (Falloon, 2020; Scherer et al., 2023; Teo et al., 2021). In the context of Society 5.0, technology is not merely a technical tool but a medium that influences the quality of pedagogical interactions, learning experiences, and schools' ability to respond to the needs of the digital generation (Antonova et al., 2024; Yamada, 2023). However, various international reports indicate that an improvement in the quality of teaching practices has not always accompanied increased access to technology. In many schools, technology is available, but its use is often limited to distributing materials, managing learning administration, or basic communication, so the potential for more substantive pedagogical transformation has not yet been fully realized (Scherer et al., 2023; Zhao et al., 2024).

To determine if these global challenges appeared locally, we conducted a preliminary field assessment before the main study. We visited elementary schools in DABIN III, Welahan Subdistrict, Jepara Regency. There, we observed classroom practices, talked with school principals and teachers, and completed a needs assessment with prospective participants. These steps revealed key findings. Most schools already had digital technologies, but teachers had not fully integrated them into innovative instruction. Instead, teachers used digital tools mainly for administration, sharing materials, and communication. Learner-centered digital teaching was limited. We also found wide differences in teachers' digital literacy and confidence in using technology with pedagogy and subject content. These findings suggest that improving access to technology alone is not enough to encourage innovative teaching. They highlight the need to explore how digital literacy can drive meaningful pedagogical innovation. This situation highlights an urgent need to understand the factors that enable technology not only to be used but also to be translated into innovative and meaningful learning practices.

The Technological Pedagogical Content Knowledge (TPACK) framework, developed by Mishra and Koehler (Mishra et al., 2023; Mishra & Koehler, 2006), posits that effective technology integration depends on teachers' ability to synthesize technological, pedagogical, and content knowledge into coherent instructional practices. Likewise, digital literacy extends beyond operational technological skills to encompass the capacity to critically access, evaluate, create, and apply digital information in meaningful educational contexts (Falloon, 2020; Gilster, 1997; Spante et al., 2018; Yadav, 2024). Ideally (Das Sollen), teachers with strong digital literacy should be able to transform digital technologies into innovative pedagogical practices through well-developed TPACK competencies within supportive technological environments. However, preliminary evidence (Das Sein) collected prior to this study through classroom observations, informal interviews with school principals and teachers, and an initial needs assessment conducted in elementary schools within DABIN III, Welahan Subdistrict, revealed a contrasting situation. Although most teachers routinely use digital technologies for administrative tasks, communication, and the distribution of instructional materials, only a limited number demonstrate confidence in integrating technology into learner-centered pedagogical strategies. Many teachers also reported difficulties in aligning digital tools with curriculum content and instructional objectives despite having adequate access to digital resources. These findings indicate a discrepancy between the theoretical expectation of technology-supported pedagogical integration and actual instructional practice. This discrepancy suggests that digital literacy alone may not automatically translate into innovative teaching practices, and it raises an important research question about the mechanisms by which digital competencies are transformed into pedagogically meaningful innovation.

In recent years, scholarly attention to teachers' digital competencies has increased substantially. Previous studies have consistently shown that digital literacy is positively associated with teachers' readiness to adopt educational technologies, develop digital-based instructional strategies, and adapt to rapidly changing learning environments (Çebi et al., 2022; Chun et al., 2021; Demissie et al., 2022). Other studies have further demonstrated that digital competence contributes to teachers' pedagogical capacity to integrate technology more effectively into classroom instruction (Cui & Zhang, 2022; Dinçer, 2024). Collectively, this body of research confirms the important role of digital literacy in supporting digital educational transformation. However, existing studies have predominantly conceptualized digital literacy as an individual capability that directly influences teaching quality, providing a limited explanation of the pedagogical mechanisms through which digital competencies are translated into innovative instructional practices. Consequently, it remains unclear how teachers' digital literacy interacts with accessible technological environments and pedagogical competencies to generate sustainable teaching innovation. Addressing this limitation is essential because educational transformation depends not only on teachers' digital skills but also on the processes that enable those skills to be effectively enacted in authentic classroom contexts. Therefore, this study proposes an integrated model that examines the sequential relationships among digital literacy, low-code pedagogical ecosystems, TPACK, and innovative teaching practices. By doing so, the study extends the TPACK literature beyond its traditional focus on individual competence, demonstrating how supportive technological ecosystems facilitate the transformation of digital capabilities into pedagogically meaningful innovation in primary education.

At the same time, various studies on the use of digital platforms in education have also emerged. Recent studies indicate that platforms that are simple, easily accessible, and do not require advanced technical skills tend to be more readily adopted by teachers than complex systems (Hafis & Kasmirah, 2024; Ibrahim et al., 2025). One technology gaining attention is the microsite, a digital space that integrates various learning resources into a single, structured environment. Previous research has generally highlighted microsites as a learning medium that supports accessibility, effectiveness, and the digital learning experience (Amrah et al., 2025; Ibrahim et al., 2025; T. Taufikin, Nurhayati, et al., 2025). However, most of these studies still focus on the instructional function of microsites as learning tools. Existing studies predominantly examine digital literacy as an individual competence and microsites as instructional tools, while paying limited attention to how accessible digital ecosystems facilitate the transformation of teachers' digital competence into pedagogical innovation.

Although the literature on digital literacy, digital learning platforms, and TPACK continues to grow, the relationship among these three areas still leaves significant academic ground to be explored (Falloon, 2020; Mishra & Koehler, 2006; Scherer et al., 2023). Previous research has not sufficiently addressed how low-code digital environments support the translation of teachers' digital literacy into pedagogical competence and innovative teaching practices (Instefjord & Munthe, 2017; Koehler et al., 2013). Most studies examine the direct relationship between digital competence and technology integration, while the mechanisms explaining this transformation process remain relatively limited (Scherer et al., 2023). Furthermore, few studies simultaneously link digital literacy, microsites as digital pedagogical environments, TPACK competencies, and innovative teaching practices within a single integrated empirical model (Voogt & Roblin, 2012). Little is known about the extent to which microsite-based pedagogical ecosystems contribute to strengthening teachers' TPACK and, in turn, to shaping innovative teaching practices in primary education settings (Howard et al., 2021). These limitations are significant because digital educational transformation is determined not only by teachers' ability to understand technology but also by the existence of a technological environment that enables these competencies to be effectively applied in daily learning activities. Therefore, this study is relevant and cannot be overlooked in efforts to understand the dynamics of digital pedagogical transformation better.

Based on this gap, this study examines the relationship between digital literacy, the low-code pedagogical ecosystem (microsite), Technological Pedagogical Content Knowledge (TPACK), and innovative teaching practices among elementary school teachers. Specifically, this study investigates how digital literacy relates to the use of microsites, how microsites relate to TPACK competencies, and how these competencies contribute to innovative teaching practices. This study also examines the mediating roles of microsites and TPACK in explaining the process of digital pedagogical transformation. Using a quantitative approach through an explanatory survey and Structural Equation Modeling–Partial Least Squares (SEM-PLS) analysis, this study offers empirical insights into the mechanisms linking digital competencies, technological environments, and learning innovation. Theoretically, this study extends the TPACK discussion by highlighting the importance of technology accessibility in developing digital pedagogical competencies. Practically, this study provides a more contextual understanding of the development of teacher competency enhancement programs and the design of more inclusive educational technology. Socially, this study indicates that sustainable digital educational transformation requires a balance between individual teacher capacity and a technological environment that supports innovative learning practices. Therefore, a methodological approach is needed to systematically, measurably, and empirically explain the relationships among these variables.

Based on the theoretical framework and the proposed conceptual model, this study formulates the following hypotheses:

H1: Digital literacy positively influences the utilization of the low-code pedagogical ecosystem (microsite).

H2: The utilization of the low-code pedagogical ecosystem (microsite) positively influences teachers' TPACK competencies.

H3: TPACK competencies positively influence innovative teaching practices.

H4: Digital literacy positively influences teachers' TPACK competencies.

H5: The utilization of the low-code pedagogical ecosystem (microsite) positively influences innovative teaching practices.

H6: TPACK competencies mediate the relationship between the low-code pedagogical ecosystem (microsite) and innovative teaching practices.

H7: The low-code pedagogical ecosystem (microsite) mediates the relationship between digital literacy and TPACK competencies.

METHODS

This study employs a post-positivist paradigm with a quantitative approach using an explanatory survey design. This design was chosen because the study not only seeks to describe the phenomenon of digital pedagogical transformation in elementary education but also examines the empirical relationships among variables that are theoretically expected to be interrelated, namely digital literacy, the low-code pedagogical ecosystem (microsite), Technological Pedagogical Content Knowledge (TPACK), and innovative teaching practices. The explanatory survey approach allows researchers to obtain a systematic picture of the patterns of relationships between variables in a real educational context while testing the conceptual model built based on the TPACK framework, digital literacy, and learning innovation (Cohen et al., 2017; Creswell & Creswell, 2022).

This study adopts a causal model that links teachers' digital competencies to innovative teaching practices through two mediating mechanisms: the use of microsites as a low-code pedagogical ecosystem and TPACK competencies. Thus, the study design not only evaluates the direct effects between variables but also identifies the pathways of digital pedagogical transformation that occur in everyday teaching practices.

To test the conceptual model simultaneously, the study employed Structural Equation Modeling–Partial Least Squares (SEM-PLS). This approach was chosen because it is suitable for educational research focused on developing predictive models, involves several interrelated latent constructs, and can provide stable estimates with relatively small sample sizes (Hair & Alamer, 2022). Additionally, SEM-PLS allows for the evaluation of the measurement and structural models in an integrated manner, thereby providing a more comprehensive understanding of the dynamics of relationships among the study variables.

The study was conducted at elementary schools within DABIN III in Welahan Subdistrict, Jepara Regency, Central Java, Indonesia. This area was selected because it represents elementary schools currently in a transitional phase toward digital learning, driven by the implementation of the Merdeka Curriculum, increased access to educational technology, and the growing use of internet-based learning platforms.

Most schools already have access to the internet and adequate digital devices. However, the level of technology integration in teaching practices still varies considerably. Some teachers have been actively developing digital-based learning, while others still use technology only to a limited extent for distributing materials and managing administrative tasks. These conditions make the research site relevant to understanding how teachers' digital competencies and the technological environment they use relate to the development of innovative teaching practices.

The study population consisted of all active elementary school teachers affiliated with DABIN III in Welahan Subdistrict during the 2025/2026 school year, totaling 104 individuals. The sample size was determined using the Slovin formula at a 5% margin of error, resulting in 83 respondents who met the study criteria.

The sampling technique used was proportional stratified random sampling to ensure that each school received proportional representation based on its number of teachers. This approach was chosen to enhance external validity and minimize representational bias. Inclusion criteria included: active elementary school teachers, involved in digital-based learning for at least the last semester, having used digital platforms or media in the learning process, and willing to participate in the study voluntarily. Teachers who were on extended leave or not actively teaching during the study period were not included in the data collection.

Table 1. Characteristics of Research Participants

Characteristics	**Category**	**n**
Gender	Male	28
	Female	55
Age	24–35 years	31
	36–45 years	29
	46–56 years	23
Teaching Experience	2–10 years	27
	11–20	34
	21–31 Years	22
Intensity of Technology Use	High	26
	Moderate	39
	Low	18

The diversity of these characteristics provides a relatively representative picture of the conditions faced by elementary school teachers in dealing with the digital education transformation.

Data were collected over four months, January to April 2026, using a structured self-administered questionnaire. The questionnaire used a five-point Likert scale (1 = strongly disagree; 5 = strongly agree) (Anjaria, 2022; Koo & Yang, 2025) and was developed through a systematic multi-stage process to ensure conceptual accuracy and measurement validity.

In the first stage, we identified measurement items by extensively reviewing literature on digital literacy, low-code pedagogical ecosystems, TPACK, and innovative teaching practices. We adapted only indicators consistently validated in educational technology studies for primary education. We modified the wording of items to reflect teachers' instructional practices while preserving the original constructs' meanings.

In the second stage, experts established content validity. Three specialists—one in educational technology, one in curriculum and instruction, and one in educational research methodology—each independently evaluated the relevance, clarity, representativeness, and appropriateness of every measurement item for its construct. Based on their feedback, several items were revised for linguistic clarity, contextual relevance, and conceptual consistency before finalizing the questionnaire.

In the third stage, the revised questionnaire was pilot-tested with 30 elementary school teachers not included in the main sample. The pilot study evaluated item clarity, response consistency, completion time, and the instrument's overall comprehensibility. Feedback from this stage led to minor revisions to item wording. These revisions did not alter the construct's conceptual structure. The final instrument consisted of four latent constructs. Digital Literacy used eight indicators adapted from Gilster (1997) and Falloon (2020): information literacy, digital communication, collaboration, content creation, safety, problem-solving, and adaptability. The Low-Code Pedagogical Ecosystem (Microsite) used eight indicators: accessibility, usability, flexibility, integration of resources, pedagogical support, and instructional efficiency, adapted from recent studies (Amrah et al., 2025; Hafis & Kasmirah, 2024; Ibrahim et al., 2025). TPACK used seven indicators measuring teachers' integration of technological, pedagogical, and content knowledge, based on Mishra and Koehler (2006) and their recent extension (Mishra et al., 2023). Innovative Teaching Practice used seven indicators: learner-centered instruction, digital creativity, collaborative and personalized learning, interactive assessment, instructional innovation, and reflective practice, synthesized from contemporary literature.

Data analysis was conducted using SmartPLS 4 software with the SEM-PLS approach. The analysis was carried out in two main stages: measurement model evaluation (outer model) and structural model evaluation (inner model) (Hair & Alamer, 2022). The measurement model evaluation was used to test the validity and reliability of the constructs. Convergent validity was evaluated using outer loadings (> 0.70) and Average Variance Extracted (AVE > 0.50). Construct reliability was evaluated using Cronbach's Alpha, rho_A, and Composite Reliability (CR > 0.70). Discriminant validity was tested using the Heterotrait-Monotrait Ratio (HTMT < 0.90).

The structural model was evaluated by examining path coefficients, t-statistics, p-values, effect size (f^2), coefficient of determination (R^2), predictive relevance (Q^2), and the Standardized Root Mean Square Residual. Hypothesis testing was performed using a bootstrapping procedure with 5,000 subsamples, a significance level of α =

0.05, and a t-statistic value > 1.96 as the basis for hypothesis acceptance. In addition to direct effects, this study examined indirect effects using mediation analysis to understand the mechanism by which digital literacy transforms into innovative learning practices.

RESULT AND DISCUSSION

Result

Measurement Model Evaluation

The measurement model was evaluated to ensure that all latent constructs satisfied the validity and reliability criteria recommended for SEM-PLS analysis. Specifically, the assessment included indicator reliability, internal consistency reliability, convergent validity, and discriminant validity before evaluating the structural relationships among the constructs.

Table 2. Outer Loadings of Measurement Items

Construct	Item	Loading
Digital Literacy (DL)	DL1	0.877
	DL2	0.773
	DL3	0.761
	DL4	0.773
	DL5	0.830
	DL6	0.754
	DL7	0.823
	DL8	0.762
Innovative Teaching Practice (ITP)	ITP1	0.822
	ITP2	0.815
	ITP3	0.742
	ITP4	0.756
	ITP5	0.822
	ITP6	0.831
	ITP7	0.852
Low-Code Pedagogical Ecosystem (ME)	ME1	0.719
	ME2	0.787
	ME3	0.802
	ME4	0.790
	ME5	0.727
	ME8	0.746
TPACK	TP1	0.837
	TP2	0.828

Construct	Item	Loading
	TP3	0.865
	TP4	0.794
	TP5	0.800
	TP6	0.755
	TP7	0.802

All measurement indicators exceeded the recommended outer loading threshold of 0.70, indicating satisfactory indicator reliability. The highest loading was observed for DL1 (0.877), suggesting that this indicator most strongly represented teachers' digital literacy, whereas ME1 (0.719) showed the lowest acceptable loading while remaining above the recommended minimum criterion. Although several indicators were close to the lower acceptable boundary, they continued to demonstrate sufficient convergent contribution to their respective constructs and were therefore retained in the final measurement model. These findings indicate that all observed variables adequately represented the theoretical constructs underlying digital literacy, the low-code pedagogical ecosystem, TPACK, and innovative teaching practices.

Table 3. Reliability and Convergent Validity

Construct	Cronbach's Alpha	rho_A	Composite Reliability	AVE
DL	0.917	0.921	0.932	0.632
ITP	0.910	0.912	0.929	0.651
ME	0.856	0.863	0.893	0.581
TP	0.914	0.916	0.931	0.660

The reliability assessment demonstrated strong internal consistency across all latent constructs. Cronbach's Alpha, rho_A, and Composite Reliability values consistently exceeded the recommended threshold of 0.70, indicating that the measurement items reliably captured the intended constructs. Furthermore, all Average Variance Extracted (AVE) values exceeded 0.50, confirming satisfactory convergent validity.

Among the constructs, Digital Literacy exhibited the highest Composite Reliability (CR = 0.932), indicating a highly consistent measurement of teachers' digital competencies. Similarly, TPACK showed excellent internal consistency (CR = 0.931), reflecting the robustness of the indicators used to measure teachers' integrative technological, pedagogical, and content knowledge. These results suggest that the measurement instrument provides stable and reliable estimates suitable for subsequent structural model analysis.

Table 4. Fornell–Larcker Criterion

Construct	DL	ITP	ME	TP
DL	0.795			
ITP	0.574	0.807		
ME	0.627	0.632	0.762	
TP	0.608	0.806	0.628	0.812

The discriminant validity assessment based on the Fornell–Larcker criterion indicated satisfactory construct distinctiveness. For every construct, the square root of the AVE exceeded the correlations with all other constructs, demonstrating that each latent variable shared more variance with its own indicators than with other constructs in the model. These findings indicate that Digital Literacy, Low-Code Pedagogical Ecosystem, TPACK, and Innovative Teaching Practice represent conceptually distinct dimensions of digital pedagogical transformation rather than overlapping constructs.

Table 5. HTMT Ratio

Construct	DL	ITP	ME	TP
DL	–			
ITP	0.621	–		
ME	0.692	0.704	–	
TP	0.659	0.878	0.702	–

The Heterotrait–Monotrait Ratio (HTMT) further confirmed discriminant validity. All HTMT values remained below the conservative threshold of 0.90, indicating that multicollinearity among latent constructs was not a concern. Although the relationship between TPACK and Innovative Teaching Practice (HTMT = 0.878) approached the upper threshold, it remained within the acceptable range, suggesting that these constructs are theoretically related while remaining empirically distinguishable.

Overall, the measurement model fulfilled all recommended criteria for indicator reliability, construct reliability, convergent validity, and discriminant validity, thereby providing a sound basis for evaluating the structural relationships.

Structural Model Evaluation

Following the establishment of measurement quality, the structural model was assessed using the coefficient of determination (R^2) and effect size (f^2).

Table 6. Coefficient of Determination (R^2)

Endogenous Construct	R^2	Adjusted R^2
Innovative Teaching Practice (ITP)	0.678	0.665
Low-Code Pedagogical Ecosystem (ME)	0.394	0.386
TPACK	0.470	0.457

The structural model demonstrated satisfactory explanatory power across all endogenous constructs. The proposed model explained 67.8% of the variance in Innovative Teaching Practice (R^2 = 0.678), indicating substantial explanatory capability. This finding suggests that Digital Literacy, the Low-Code Pedagogical Ecosystem, and TPACK collectively account for a considerable proportion of teachers' innovative instructional practices within the investigated educational context.

In addition, Digital Literacy explained 39.4% of the variance in the Low-Code Pedagogical Ecosystem (R^2 = 0.394), indicating that teachers' digital competencies substantially influence their ability to adopt and utilize accessible digital learning environments. Likewise, Digital Literacy and the Low-Code Pedagogical Ecosystem jointly explained 47.0% of the variance in TPACK (R^2 = 0.470), demonstrating that teachers' pedagogical technological competence develops through the interaction between individual digital capability and a supportive technological environment.

Although these values indicate substantial predictive capacity, the unexplained variance also suggests that other contextual factors—such as school leadership, organizational support, institutional digital culture, and professional development opportunities—may further contribute to teachers' innovative teaching practices and should therefore be explored in future studies.

Table 7. Effect Size (f^2)

Relationship	f^2
DL → ME	0.649
DL → TP	0.143
ME → TP	0.189
DL → ITP	0.006
ME → ITP	0.053
TP → ITP	0.702

The effect size analysis provides important information regarding the practical significance of each structural relationship beyond statistical significance alone.

Digital Literacy exerted a large effect on the Low-Code Pedagogical Ecosystem (f^2 = 0.649), indicating that teachers' digital competencies strongly determine their capacity to utilize accessible digital learning environments. This finding implies that investments in improving teachers' digital literacy are likely to yield substantial gains in technology adoption and utilization in schools.

By contrast, Digital Literacy demonstrated only a small direct effect on TPACK (f^2 = 0.143) and an almost negligible direct effect on Innovative Teaching Practice (f^2 = 0.006). Similarly, the Low-Code Pedagogical Ecosystem exerted only a small direct effect on Innovative Teaching Practice (f^2 = 0.053). These findings suggest that neither digital competence nor technology availability alone is sufficient to generate meaningful pedagogical innovation.

The strongest practical effect was observed for the relationship between TPACK and Innovative Teaching Practice (f^2 = 0.702). According to Cohen's classification, this represents a very large practical effect, demonstrating that teachers' ability to integrate technological, pedagogical, and content knowledge is the primary mechanism through which digital transformation translates into innovative classroom practice.

From a practical perspective, these findings indicate that educational policies that emphasize only digital infrastructure or technical training may yield limited instructional innovation unless accompanied by systematic efforts to strengthen teachers' competencies in pedagogical integration.

Predictive Assessment

Predictive relevance was evaluated using the blindfolding procedure.

Table 8. Predictive Relevance (Q^2)

Construct	SSO	SSE	Q^2
DL	664,000	664,000	–
ITP	581,000	335,935	0.422
ME	498,000	388,028	0.221
TP	581,000	405,694	0.302

All endogenous constructs produced positive Q^2 values, confirming that the structural model possesses satisfactory predictive relevance.

The highest predictive relevance was observed for Innovative Teaching Practice (Q^2 = 0.422), indicating that the proposed conceptual model has strong predictive capability in explaining teachers' innovative instructional behavior. Meanwhile, TPACK (Q^2 = 0.302) and the Low-Code Pedagogical Ecosystem (Q^2 = 0.221) also demonstrated satisfactory predictive performance, suggesting that the model adequately captures the mechanisms linking digital literacy, technological environments, and pedagogical competencies.

Collectively, these results indicate that the proposed model possesses not only explanatory power but also meaningful predictive capability, thereby supporting its usefulness for understanding digital pedagogical transformation in primary education.

Hypothesis Testing

Hypothesis testing was conducted using bootstrapping with 5,000 resamples. The mediation analysis provides a more comprehensive understanding of the mechanisms underlying digital pedagogical transformation.

First, the indirect relationship between Digital Literacy and Innovative Teaching Practice through the Low-Code Pedagogical Ecosystem alone did not reach statistical significance (β = 0.115, p = 0.059). This finding indicates that the availability of an accessible digital platform, by itself, is insufficient to stimulate innovative instructional practices. Although microsites facilitate technology use, they do not automatically transform teachers' digital competencies into pedagogical innovation.

Table 9. Indirect Effects and Mediation Analysis

Path	β	t-value	p-value	Result
DL → ME → ITP	0.115	1.893	0.059	Not Supported
DL → TP → ITP	0.231	3.436	0.001	Supported
ME → TP → ITP	0.266	4.066	0.000	Supported
DL → ME → TP → ITP	0.167	3.384	0.001	Supported
DL → ME → TP	0.255	3.507	0.000	Supported

Second, TPACK emerged as the dominant mediating mechanism within the proposed conceptual model. The indirect pathway Digital Literacy → TPACK → Innovative Teaching Practice was positive and statistically significant (β = 0.231, p = 0.001), demonstrating that improvements in teachers' digital literacy become educationally meaningful only after being translated into integrated technological, pedagogical, and content knowledge.

Similarly, the pathway Low-Code Pedagogical Ecosystem → TPACK → Innovative Teaching Practice was also significant (β = 0.266, p < 0.001), indicating that user-friendly technological environments contribute to instructional innovation primarily by strengthening teachers' pedagogical competencies rather than merely increasing technology usage.

The most important finding emerged from the serial mediation pathway involving Digital Literacy → Low-Code Pedagogical Ecosystem → TPACK → Innovative Teaching Practice (β = 0.167, p = 0.001). This result demonstrates that digital pedagogical transformation occurs through a progressive developmental process rather than a simple direct relationship. Teachers first develop digital literacy, subsequently adopt supportive technological ecosystems, then strengthen their TPACK competencies, and ultimately translate these competencies into innovative classroom practices.

Taken together, these findings indicate that innovative teaching practice is not determined solely by digital competence or technology availability. Rather, it emerges through a sequential transformation process in which digital literacy, supportive technological ecosystems, and pedagogical integration competencies reinforce one another. The results, therefore, provide empirical evidence that sustainable digital educational transformation requires simultaneous investment in teachers' digital capabilities, accessible technological environments, and the development of pedagogical competencies, thereby extending the current understanding of how technology contributes to meaningful educational innovation.

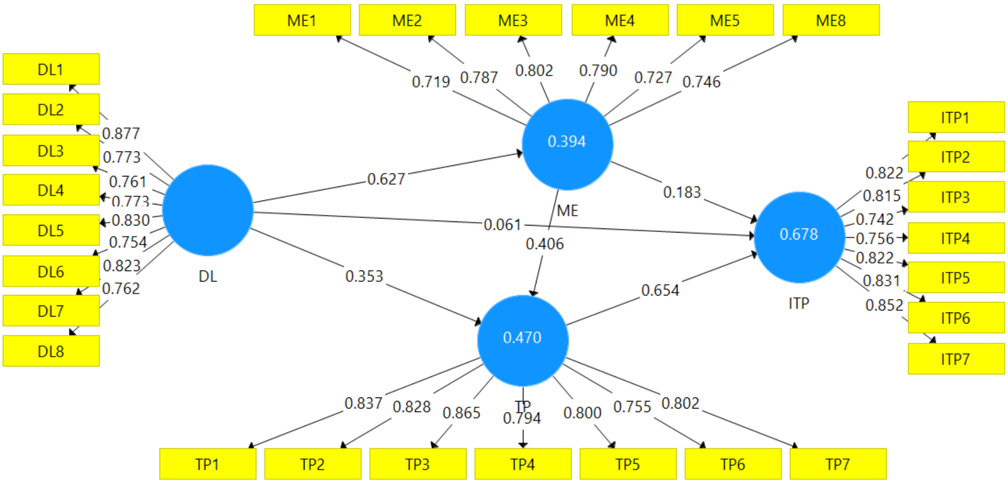

Figure 1 Structure model

Discussion

The findings show that digital transformation in primary education does not result directly from teachers' digital skills or access to technology. Instead, digital literacy (the ability to use and evaluate digital information), low-code ecosystems (software environments that allow teachers to build applications with minimal coding), and TPACK skills (Technological Pedagogical Content Knowledge: teachers' understanding of how technology integrates with pedagogy and content) interact to drive innovative teaching. Our model explained 67.8% of the variation in innovative practices, confirming its ability to identify key factors. Most importantly, technological innovation relies on teachers using digital resources to guide instructional decisions, not just on adopting tools.

The first finding shows that digital literacy strongly influences teachers' use of the Low-Code Pedagogical Ecosystem (Microsite). This is similar to earlier studies, which found that digitally competent teachers are more willing to adopt technologies (Çebi et al., 2022; Demissie et al., 2022; T. Taufikin, Badawi, et al., 2025). The present study, however, gives a deeper explanation for this relationship. Digital literacy gives teachers not just technical skills, but also the ability to evaluate technology, identify useful tools, and confidently integrate digital resources in class. Teachers with high digital literacy see low-code environments as useful rather than overwhelming. They view microsites as tools to make learning activities easier and reduce technical workload, instead of as added burdens.

This relationship is especially important in primary education, where classroom teachers manage many responsibilities. Unlike secondary teachers, elementary teachers cover all subjects, organize classrooms, assess students, support social and emotional growth, and communicate with parents. These multiple duties leave little time to master complex learning platforms. As a result, simple, accessible digital platforms become more practical and appealing. The strong tie between digital literacy and microsite use may reflect not only teachers' digital skills, but also the demands of elementary education. Easy-to-use tools are crucial for sustainable tech integration in this context.

The findings expand Gilster's idea of digital literacy. It's not just technical skill, but also helps teachers select tools that best fit their teaching. The results support Falloon's theory that digital competence means making smart tech choices for each situation. This study shows digital literacy sparks innovation by guiding teachers to choose tech ecosystems that support their teaching.

The second finding shows that the Low-Code Pedagogical Ecosystem boosts teachers' TPACK skills. Earlier studies saw training and experience as the main sources of TPACK (Koehler et al., 2013; Mishra et al., 2023). This study, though, suggests the tech environment also matters. User-friendly systems lower the cognitive load of using technology. This frees teachers to plan lessons, interact with students, and reflect on teaching. Teachers spend more energy on integrating technology into teaching and content, not battling technical barriers. This finding shows TPACK grows from both professional learning and ongoing use of tech designed for pedagogical support.

TPACK drives new teaching practices, as shown by its large effect size. Tech skills alone do not spark innovation. Innovation happens when teachers combine technology, teaching methods, and subject knowledge. This proves TPACK's core idea. Strong TPACK helps teachers choose the right technology, tailor lessons, and make learning engaging. Teacher development should focus on building TPACK, not just tech exposure.

The mediation analysis gives more insight into digital change. However, the pathway from Digital Literacy to Innovative Teaching through Microsite did not matter. In other words, providing easy platforms alone does not drive new teaching. While accessible tech supports classroom management and content sharing, it does not guarantee innovation. This finding challenges the belief that more tech always improves teaching. Ultimately, innovation requires teachers who use technology meaningfully.

In contrast, TPACK is the main mediating factor. Strong TPACK directly links digital literacy and tech environments to innovation. These results align with earlier

TPACK research, showing that transformation occurs when teachers combine tech, teaching, and content skills. TPACK ties digital skills to educational innovation, not just classroom routines.

The study's big contribution is the pathway: Digital Literacy → Low-Code Pedagogical Ecosystem → TPACK → Innovative Teaching. The importance of this path shows that digital change is a step-by-step process, not a direct one. Teachers first gain digital skills to choose the right tech. These tools then help them build TPACK, which leads to new teaching practices. This process shows that digital transformation is a mix of connected skills, not just a series of separate actions. The findings expand beyond the idea that digital literacy, educational technology, and TPACK are unrelated, showing they are linked stages in a continuous transformation.

This study makes several theoretical contributions. It extends the TPACK framework by showing that teacher growth relies on training and tech environments. It frames microsites as ecosystems that let teachers make choices with less technical trouble. It proposes a sequence: digital literacy leads to new teaching through strong tech and integration skills. These insights deepen the understanding of digital transformation while keeping the current theory.

The findings have important practical implications. Teacher development should go beyond digital skills training. It should also strengthen digital literacy, TPACK, and teachers' ability to use accessible tech. Policymakers should see that digital transformation needs both the right infrastructure and technologies that are easy to use in daily teaching. In primary education, where teachers juggle many duties and tight schedules, low-code ecosystems may offer a better path to innovation than complex digital platforms.

The findings show that sustainable digital transformation in education needs a balance between teachers' skills and tech environments. Digital literacy prepares teachers for tech adoption. Low-code ecosystems support everyday teaching. TPACK turns these abilities into innovative practices. This view helps us better understand digital change and can guide future teacher development and tech planning.

This study has several limitations that should be considered when interpreting the findings. First, the study employed a cross-sectional survey design using self-reported questionnaires, which may be subject to common method bias and social desirability bias because all variables were measured from the same respondents at a single point in time. Therefore, although the SEM-PLS results support the proposed relationships, they should be interpreted as predictive associations rather than definitive evidence of causality. In addition, the study was conducted within a single elementary school cluster in Jepara Regency, which may limit the generalizability of the findings to other educational contexts.

Future research is encouraged to employ longitudinal or mixed-methods designs by combining survey data with classroom observations, interviews, or learning analytics to reduce potential self-report bias and provide stronger evidence of causal relationships. Expanding the research across different regions and incorporating contextual variables, such as school leadership, organizational culture, institutional digital readiness, and professional support, would further strengthen the understanding of digital pedagogical transformation across diverse educational settings (Hallinger & Heck, 2010; Hallinger & Kovačević, 2022; OECD, 2021; M. S. I. Taufikin et al., 2024; UNESCO, 2023).

CONCLUSION

This study demonstrates that digital pedagogical transformation in primary education is a progressive and interconnected process rather than a direct consequence of teachers' digital literacy. The SEM-PLS results show that the proposed model explained 67.8% of the variance in innovative teaching practices, highlighting substantial explanatory power. Although digital literacy strongly promoted the adoption of the Low-Code Pedagogical Ecosystem (Microsite), innovative teaching practices emerged primarily through the mediating role of TPACK, while the direct mediation through the microsite alone was not significant. Furthermore, the significant serial mediation pathway (Digital Literacy → Microsite → TPACK → Innovative Teaching Practice) demonstrates that digital competencies contribute to instructional innovation only when teachers are able to integrate technology, pedagogy, and content within a supportive technological environment. These findings extend the TPACK framework by demonstrating that the development of digital pedagogical competence depends not only on teachers' individual capabilities but also on the characteristics of user-friendly technological ecosystems that facilitate pedagogical integration.

The findings have important implications for both educational theory and practice. Theoretically, this study advances the literature by seeing microsites as low-code pedagogical ecosystems. This extends current views that mostly see them as instructional media. Practically, the results suggest that teacher professional development should go beyond digital skills training. It should also emphasize building digital literacy, TPACK competencies, and access to user-friendly technological environments. For schools and policymakers, investments should focus on simple, adaptable, and instructionally meaningful technologies. They should also provide ongoing professional support that helps teachers use technology in learner-centered pedagogy. These findings provide an empirical basis for designing more effective digital transformation strategies in primary education. They also offer a framework to be tested and refined in broader educational contexts.

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