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Digital Transformation In Learning Environments: Roles Of Management Support, Leadership, And Literacy

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Abstract

Schools increasingly possess digital facilities, yet many have not developed the organizational capability to deliver digital learning consistently. Drawing on the Resource-Based View and Dynamic Capabilities theory, this study explains how management support, digital leadership, and digital literacy relate to the digital learning environment, reconceptualized as an organizational capability, with digital transformation positioned as the conversion mechanism. A quantitative explanatory, cross-sectional design was applied to 302 senior high school teachers in DKI Jakarta, Indonesia, selected through multistage sampling with proportional allocation followed by purposive selection, with prior instructional technology training as the inclusion criterion. Data on 51 indicators were analyzed using Partial Least Squares Structural Equation Modeling. All ten hypotheses were supported. Digital leadership showed the strongest path to digital transformation (β = 0.420), whereas digital literacy had the largest direct relationship with the digital learning environment (β = 0.311). All three indirect paths were significant and constituted complementary partial mediation, with variance accounted for ranging from 16.4% to 30.9%. The model explained 64.8% of the variance in digital transformation and 64.6% in the digital learning environment. The findings are summarized as a Digital Learning Capability Pyramid and are interpreted as explanatory rather than causal relationships. Practically, strengthening principals' digital leadership and teachers' digital competence warrants higher priority than adding facilities.

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Keywords: Management Support; Digital Leadership; Digital Literacy; Digital Transformation; Digital Learning Environment.

INTRODUCTION

Digital transformation in education has become a strategic global priority. It constitutes a systemic process involving institutional restructuring, technology adoption, and organizational culture change to enhance learning quality (Tai & Son, 2023). Digitalization in education extends beyond technological applications; it represents a comprehensive paradigm shift that requires transforming institutional strategies, governance, and learning methods to meet the demands of the digital era. The UNESCO report emphasizes that digital technology is no longer a supplementary tool but a key instrument to accelerate the achievement of Sustainable Development Goal 4 (SDG 4) on quality education. The use of technology has been shown to expand access, increase inclusion, and strengthen education governance (UNESCO, 2023). The OECD highlights the importance of building an effective digital education ecosystem, emphasizing learning personalization, cost efficiency, and inclusion, while warning about access gaps and ethical challenges (OECD, 2023). Beyond international policy considerations, successful digital transformation in educational institutions depends on management support, including resource provision, institutional commitment, and consistent organizational strategies for technology integration. The conditions affirmed by UNESCO and OECD indicate that digital transformation in education has shifted from a policy option to a strategic imperative. Consequently, schools and educational institutions can no longer delay technological integration, as digitalization is now the primary means to ensure access, inclusion, and sustainable education governance.

Research by Feng et al. (2025) found that adopting educational technology can be effective when management provides an adequate policy framework, training, and infrastructure. In line with that, the research by Alenezi (2023) demonstrated that digital transformation in education encompasses not only technology use but also process restructuring, governance, and institutional strategies. Without robust management support, institutional readiness for technology integration remains low, risking failure in sustainable digital educational transformation. Concurrent with the accelerated adoption of digital technology across sectors, digital leadership has emerged as a paradigm-shaping force in organizational success, including in education. Digital leadership is a strategic capacity to build vision, manage change, and foster a culture of innovation that enables effective technology integration in schools (Karakose et al.,

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2024; Okunlola & Naicker, 2025). Digital transformation in education establishes digital literacy as a primary prerequisite for teachers to integrate technology effectively into learning. Digital literacy is a core competency determining teachers' readiness to navigate educational transformation through technology. These competencies include technical, critical, ethical, and productive skills to foster pedagogical innovation. Alenezi (2023) further emphasizes that digital transformation involves restructuring processes, governance, and institutional strategies that support educators' development of digital literacy. Thus, digital transformation bridges management support, digital leadership, and digital literacy to create an adaptive and sustainable digital learning environment. Boztaş et al. (2025) found that digitalization in education constitutes a new learning modality that strengthens the relationship between institutional factors and individual competencies, thereby fostering an adequate digital learning environment. However, empirically, Indonesia still faces substantial human-factor obstacles, especially among teachers. This condition is in stark contrast to the demands of the digital era globally, where digital transformation has become the main foundation for economic, social, and educational development.

Internationally, digital transformation is widely regarded as a key prerequisite for the success of education in the current era, yet Indonesia still faces limited digital capacity, creating substantial gaps. This gap is not only a technical problem but also reflects weak technological readiness, low digital literacy, and inadequate alignment between national policies and global demands. World Bank data estimates that Indonesia needs around 9 million digitally skilled workers, and teachers are among the most affected by the gap. Teachers' unpreparedness in mastering digital skills has direct implications for the quality of the learning process and environment. This is due to an imbalance between students' increasing familiarity with digital technology and teachers' and schools' capacity to integrate technology into the learning process (DetikEdu, n.d.). If this condition is not addressed immediately, Indonesia risks falling behind in international education competitions, potentially failing to prepare the younger generation for the digital job market, and widening educational inequalities. The concept of a digital learning environment emphasizes that technology-based learning spaces are ecosystems that integrate students, teachers, and digital resources into a single system. This emphasizes that the success of digital transformation in Indonesia depends not only on infrastructure but also on strengthening human capital development, ensuring policy alignment, and increasing teachers' digital literacy, all of which are key factors in the learning process. Thus, the urgency of digital

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transformation must be seen as a strategic agenda that demands collaboration among management support, digital leadership, and digital literacy teachers to create an adaptive and sustainable digital learning environment.

In line with this urgency, the creation of an adaptive and sustainable digital learning environment heavily depends on the synergy between organizational and individual factors. Structurally, management support is believed not only to have a direct positive impact on the quality of the digital learning environment but also to serve as the primary foundation driving the successful integration of systems within educational institutions (Amikratunnisyah, 2025; Nguyen & Tuamsuk, 2022). Based on this argument, this study hypothesizes that managerial support has a positive and significant effect on digital transformation (H1) and the digital learning environment (H2) (Zou et al., 2025; Ly et al., 2024). At other managerial levels, digital leadership offers strategic capacity in guiding innovation and building an adaptive organizational culture (Figueroa et al., 2025). Leadership that is adaptive to technology is postulated to be crucial in accelerating technology adoption while strengthening the learning ecosystem (Zhu et al., 2025; Peng et al., 2024). Therefore, it is hypothesized that digital leadership has a positive and significant effect on digital transformation (H3) and the digital learning environment (H4) (Okunlola & Naicker, 2025; Anengsih et al., 2025). Furthermore, at the individual level, digital literacy serves as a fundamental competency that bridges the technology adoption gap (Gaytan et al., 2023). Adequate digital understanding and proficiency not only have direct implications for the effectiveness of pedagogical interactions but are also essential prerequisites for the success of comprehensive systemic change (Yuan et al., 2025). Thus, this study posits that digital literacy has a positive and significant effect on digital transformation (H5) (Septiari et al., 2025; Megasafitri et al., 2023; Pascua-Valenzuela, 2025) and the digital learning environment (H6) (Tinmaz et al., 2022; Atmaja et al., 2024).

Furthermore, digital transformation in the context of this study is not merely positioned as a driving variable, but rather as a strategic mechanism that is empirically capable of boosting the overall quality of the educational ecosystem (McCarthy et al., 2023; Khanal & Pokhrel, 2024; Jarukasetwit et al., 2024). Therefore, it is hypothesized that digital transformation has a direct, positive, and significant influence on the digital learning environment (H7) (Nguyen & Tuamsuk, 2022). Within this Structural Equation Modeling (SEM) paradigm, digital transformation is projected to play a crucial role as a mediating variable bridging the antecedent factors (Tai & Son, 2023; Onan, 2024; Vuorikari et al., 2022). Based on this conceptual framework, a mediation

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hypothesis is proposed that managerial support (H8), digital leadership (H9), and digital literacy (H10) each have a positive and significant influence on the digital learning environment through the mediating role of digital transformation (Dahiya et al., 2025).

The concept of the digital learning environment emerged in response to the limitations of traditional approaches, such as behaviorism and cognitivism, by prioritizing collaboration, personalization, and interconnectedness in digital learning (Downes, 2023). While this framework serves as a strategic foundation for building an adaptive and sustainable education system, a significant discrepancy exists in Indonesia between global digital demands and actual educational capacities. Specifically, limitations in teachers' digital literacy and inadequate school management support hinder the development of an ideal ecosystem, necessitating a stronger alignment between international benchmarks and national education strategies. This situation reveals a critical research gap regarding the dynamic relationship between organizational factors and individual competencies in secondary education. Empirical studies that comprehensively examine how management support, digital leadership, and digital literacy interact through digital transformation mechanisms to form a sustainable learning environment remain scarce. To bridge this gap, and drawing on the Resource-Based View and Dynamic Capabilities theory (Barney, 1991; Teece, 2007), this research reconceptualizes the digital learning environment as an organizational capability, namely the school's ability to deliver digital learning, rather than as a container, a set of facilities, or an ecosystem. It examines how management support (an organizational resource), digital leadership (a managerial capability), and digital literacy (digital human capital) relate to this capability directly and through digital transformation as the conversion mechanism. Ultimately, this study seeks to provide theoretical, empirical, and practical contributions by integrating these key variables into a unified conceptual framework. By offering evidence from Indonesian high schools—a relatively underexplored context—this research provides strategic recommendations for policymakers and school management to strengthen institutional readiness, enabling them to adapt and thrive amidst the complex demands of the global digital education era.

METHOD

Research Design

This research employed a quantitative, explanatory research approach to explain the hypothesized directional relationships among management support, digital leadership, digital

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literacy, digital transformation, and the digital learning environment. The explanatory design was used to examine how these variables are related and whether digital transformation functions as a mediating mechanism in the research model. The data was analyzed using Structural Equation Modeling (SEM) with the Partial Least Squares (PLS) method. The SEM-PLS method was chosen because it could investigate the complicated interactions among factors and test direct and indirect effects inside a single research model (Nguyen & Tuamsuk, 2022). To visualize these complex interactions and the specific structural paths tested within this method, a conceptual framework was developed. This model delineates the direct effects of the exogenous variables (management support, digital leadership, and digital literacy) on the endogenous variable (digital learning environment), as well as their indirect effects mediated by digital transformation. The comprehensive research framework and all hypothesized paths are illustrated in Figure 1.

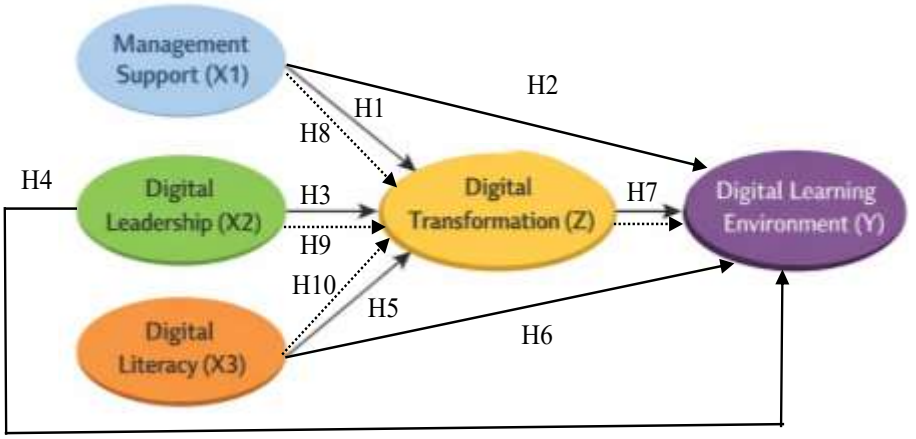


Figure 1. Conceptual Framework

The study used a cross-sectional design in which the predictors, mediator, and outcome were measured at one point in time with a single instrument. Temporal precedence among the variables therefore cannot be verified empirically, and the term “effect” in the hypotheses denotes a theoretically grounded directional relationship rather than a demonstrated causal effect; the resource–mechanism–capability ordering of the model rests on the Resource-Based View and Dynamic Capabilities theory (Barney, 1991; Teece, 2007). PLS-SEM was preferred over covariance-based SEM because the study is explanatory and predictive rather than confirmatory, the model is complex (five constructs, ten hypotheses, three mediation paths, and 51 indicators), the reconceptualized digital learning environment construct lacks an established measurement

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tradition, and the Likert-type data did not meet multivariate normality (Hair et al., 2021). The unit of analysis is the individual teacher; constructs referring to school-level phenomena were measured as teachers' perceptions of organizational conditions, and all conclusions are drawn at that level.

Sampling and Data Collection

The research population consisted of high school teachers in DKI Jakarta Province, Indonesia. Based on the data of Badan Pusat Statistik (BPS) DKI Jakarta province, the number of high school teachers reached 12,114 (BPS Provinsi DKI Jakarta, 2025). The minimum sample size was determined through an a priori statistical power analysis (four predictors at most, $\alpha = 0.05$, power = 0.80) for the smallest effect size in the model ($f^2 = 0.05$), which required at least 244 respondents (Faul et al., 2009), while the sample-size guidelines for PLS-SEM were also observed (Hair et al., 2021). Fieldwork yielded 400 completed questionnaires, which were screened against an inclusion criterion set a priori at the design stage, namely prior participation in instructional technology training. A total of 98 respondents (24.5%) reported no such training and were excluded, leaving 302 valid respondents. At n = 302, the statistical power to detect the smallest effect in the model was 0.888, although power for very small effects ($f^2 = 0.02$) was only 0.466. The sampling design was multistage sampling with proportional allocation followed by purposive selection. In the first stage, target respondents were allocated to the six administrative regions of DKI Jakarta in proportion to the number of high school teachers in each region. In the second stage, schools were purposively selected based on institutional status (public and private), accreditation (A and B), and participation in digitalization programs. In the third stage, teachers were purposively selected based on the inclusion criterion while ensuring variation in subject area and length of service. The final sample came from 39 high schools across the six regions, with about eight teachers per school, comprising 109 public-school and 193 private-school teachers. Because the last two stages were non-probabilistic, the findings are not generalized statistically to all high school teachers in DKI Jakarta but analytically to teachers with similar characteristics.

Variable Measurement

This research focused on five major constructs: management support, digital leadership, digital literacy, digital transformation, and digital learning environment. The entire construct was

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evaluated using indicators adopted from validated past research and tailored to the context of digital revolution in education. Management support included school-level policy, resource provision, and technology facilitation to help with the adoption of digital learning. This variable measurement indicator was adapted from Hertati et al. (2020). Digital leadership described the ability of leaders to integrate digital technology with the organization's strategic vision and encouraged innovation in the learning process. This variable was measured using an indicator developed by Anwar & Saraih (2024). Digital literacy referred to individuals' ability to access, understand, evaluate, and use digital technology effectively in learning activities. This variable measurement indicator was adapted from Anggoro (2025).

Digital transformation represented a fundamental change in organizational processes by integrating digital technology to improve efficiency, innovation, and the quality of educational services. The measurement of these variables used indicators adapted from Nisa et al. (2025). The digital learning environment was conceptualized as an organizational capability, namely the school's capability to deliver technology-supported learning that enables interaction among teachers, students, and digital learning resources, rather than as a container or a set of facilities. This variable indicator was adapted from Morze & Kucherovska (2020). All variables were assessed on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) and specified as reflective first-order constructs. The analyzed instrument comprised 51 items: management support (15), digital leadership (9), digital literacy (3), digital transformation (12), and digital learning environment (12). The digital literacy construct was refined to capture teachers' individual competence only; six items measuring school infrastructure availability (three) and parental support (three) were excluded from the model because they reflect conditions outside the teacher, although they remained in the questionnaire. A pre-test with 30 respondents confirmed the validity and reliability of the instrument before the main data collection.

Data Analysis Techniques

The data were analyzed using SmartPLS version 4 in three stages: measurement model evaluation (outer model), structural model evaluation (inner model), and hypothesis testing. Convergent validity was assessed through outer loadings and Average Variance Extracted (AVE), with thresholds of 0.708 and 0.50, respectively; indicators loading between 0.40 and 0.708 were retained when their removal did not raise AVE or composite reliability above the threshold (Hair

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et al., 2021). Construct reliability was examined using Cronbach's alpha and composite reliability (rho_a and rho_c), and discriminant validity was tested with the Heterotrait-Monotrait ratio (HTMT), the Fornell-Larcker criterion, and cross-loadings. Because all variables were collected from the same respondents with one instrument, common method bias was assessed using Harman's single-factor test and the full collinearity assessment approach (VIF ≤ 3.3) (Kock, 2015).

The structural model was evaluated using the inner Variance Inflation Factor (VIF) to detect collinearity, the coefficient of determination (R^2), effect size (f^2), in-sample predictive relevance (Q^2, blindfolding with omission distance D = 7), and out-of-sample predictive performance through PLSpredict with ten-fold cross-validation (Shmueli et al., 2019). The Standardized Root Mean Square Residual (SRMR) was treated only as approximate model fit information, with a threshold of 0.10 for composite-based models (Henseler et al., 2016). Hypotheses were tested by bootstrapping with 5,000 subsamples, using the path coefficients procedure for direct effects and the specific indirect effects procedure for mediation; a relationship was considered significant when $p < 0.05$ and $t > 1.96$. The type of mediation was determined following Zhao et al. (2010) and quantified with the Variance Accounted For (VAF). Robustness was examined through measurement invariance testing and multigroup analysis (MGA) between public and private schools, and by comparing the main model with an alternative model without the mediator.

RESULTS

Evaluation of the Measurement Model

Convergent validity was evaluated using outer loadings and AVE. As shown in Figure 2, the outer loadings of the 51 indicators ranged from 0.690 to 0.929. Most indicators exceeded 0.708, while a few lay between 0.690 and 0.708 (the lowest being X1-4 and X2-2 at 0.690); following Hair et al. (2021), these were retained because their removal would not raise AVE or composite reliability above the required thresholds. The highest loading in each construct was X1-11 (0.778) for management support, X2-3 (0.819) for digital leadership, X3-4 (0.929) for digital literacy, Y-9 (0.835) for the digital learning environment, and Z-10 (0.855) for digital transformation. All three items of the refined digital literacy construct loaded above 0.78, indicating a coherent representation of teachers' digital competence.

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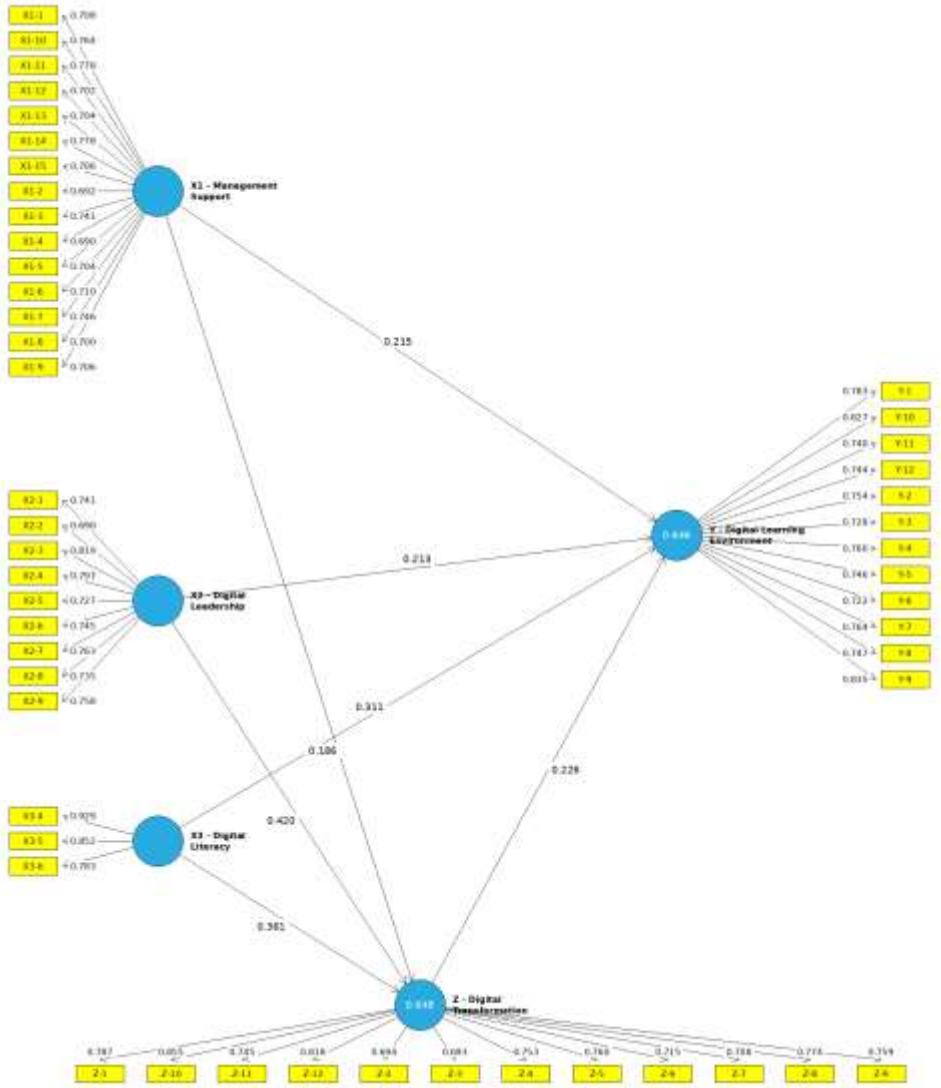


Figure 2. PLS Algorithm Results: Outer Loadings, Path Coefficients, and R^2

As presented in Table 1, all latent variables met the convergent validity criterion, with AVE values above 0.50. Digital literacy recorded the highest value (0.734), followed by the digital learning environment (0.583), digital transformation (0.572), digital leadership (0.568), and management support (0.522). Each construct therefore explains more than half of the variance in its indicators. The high AVE of digital literacy indicates that restricting the construct to teacher

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competence, by excluding infrastructure and parental support items, produced a more homogeneous measure.

Table 1. AVE Test Results

Construct	Average variance extracted (AVE)
X1 - Management Support	0.522
X2 - Digital Leadership	0.568
X3 - Digital Literacy	0.734
Y - Digital Learning Environment	0.583
Z - Digital Transformation	0.572

Discriminant validity was assessed primarily with the HTMT ratio. As shown in Table 2, all values were below both the conservative threshold of 0.85 and the liberal threshold of 0.90. The highest value was 0.787 between digital literacy and the digital learning environment, followed by 0.770 between digital literacy and digital transformation, while the lowest was 0.530 between digital leadership and management support. The Fornell-Larcker criterion and cross-loadings led to the same conclusion: the square root of each construct's AVE (0.722–0.857) exceeded its correlations with the other constructs. Empirical separation, however, does not by itself show that the constructs are correctly defined; their conceptual distinctiveness was established beforehand through the definitions, dimensions, and indicators of each construct.

Table 2. HTMT Test Results

Interaction	HTMT
X2 - Digital Leadership ↔ X1 - Management Support	0.530
X3 - Digital Literacy ↔ X1 - Management Support	0.604
X3 - Digital Literacy ↔ X2 - Digital Leadership	0.586
Y - Digital Learning Environment ↔ X1 - Management Support	0.649
Y - Digital Learning Environment ↔ X2 - Digital Leadership	0.681
Y - Digital Learning Environment ↔ X3 - Digital Literacy	0.787
Z - Digital Transformation ↔ X1 - Management Support	0.615
Z - Digital Transformation ↔ X2 - Digital Leadership	0.748
Z - Digital Transformation ↔ X3 - Digital Literacy	0.770
Z - Digital Transformation ↔ Y - Digital Learning Environment	0.756

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Reliability results are presented in Table 3. Cronbach's alpha ranged from 0.819 to 0.934, rho_a from 0.855 to 0.939, and rho_c from 0.892 to 0.944, all above the 0.70 threshold. Digital literacy showed the lowest values (α = 0.819; rho_c = 0.892), which is expected because the refined construct contains only three items and alpha rises with the number of items; its high AVE nonetheless indicates good construct quality. The instrument therefore demonstrates adequate internal consistency.

Table 3. Reliability Test Results

Construct	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)
X1 - Management Support	0.934	0.938	0.942
X2 - Digital Leadership	0.905	0.913	0.922
X3 - Digital Literacy	0.819	0.855	0.892
Y - Digital Learning Environment	0.934	0.939	0.944
Z - Digital Transformation	0.932	0.936	0.941

Structural Model Evaluation

Collinearity among the predictors was assessed using the inner VIF. As shown in Table 4, all values ranged from 1.496 to 2.842, well below the threshold of 5 and also below the stricter value of 3.3. Collinearity is therefore not a concern, and each predictor contributes distinct information to the structural model.

Table 4. VIF Inner Test Results

Route	VIF
X1 - Management Support → Y - Digital Learning Environment	1.658
X1 - Management Support → Z - Digital Transformation	1.559
X2 - Digital Leadership → Y - Digital Learning Environment	1.998
X2 - Digital Leadership → Z - Digital Transformation	1.496
X3 - Digital Literacy → Y - Digital Learning Environment	1.967
X3 - Digital Literacy → Z - Digital Transformation	1.597
Z - Digital Transformation → Y - Digital Learning Environment	2.842

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Model fit was examined with the SRMR, which was 0.092 for both the saturated and estimated models (Table 5). This value exceeds the strict 0.08 cutoff rooted in covariance-based SEM but lies below the 0.10 threshold recommended for composite-based models (Henseler et al., 2016). Because PLS-SEM is not grounded in model-fit testing, the SRMR is treated here only as approximate fit information and not as evidence that the proposed theory is correct; the assessment of model quality rests mainly on the measurement model, R^2, f^2, Q^2, and PLSpredict.

Table 5. SRMR Test Results

Metric	Saturated model	Estimated model
SRMR	0.092	0.092

The R^2 of digital transformation was 0.648 (adjusted 0.645), indicating that management support, digital leadership, and digital literacy jointly explained 64.8% of its variance. The R^2 of the digital learning environment was 0.646 (adjusted 0.641), meaning that the four predictors explained 64.6% of its variance (Table 6). Both values lie between the moderate (0.50) and substantial (0.75) benchmarks (Hair et al., 2021), leaving roughly 35% of the variance to factors outside the model.

Table 6. R^2 Test Results

Construct	R2	R2 Adjusted
Y - Digital Learning Environment	0.646	0.641
Z - Digital Transformation	0.648	0.645

Effect sizes are reported in Table 7. The largest effect was that of digital leadership on digital transformation (f^2 = 0.336, medium to large), followed by digital literacy on digital transformation (f^2 = 0.231, medium) and digital literacy on the digital learning environment (f^2 = 0.139, small to medium). Management support showed small effects on digital transformation (0.063) and the digital learning environment (0.079), as did digital leadership on the digital learning environment (0.064) and digital transformation on the digital learning environment (0.051). The pattern suggests a division of roles: digital leadership operates mainly at the level of reorganizing systems and organizational direction, whereas teachers' digital literacy acts more directly on everyday learning delivery. Management support, although significant, behaves as an enabling resource that provides preconditions rather than as the main driver of change.

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Table 7. f^2 Test Results

Route	F2
X1 - Management Support → Y - Digital Learning Environment	0.079
X1 - Management Support → Z - Digital Transformation	0.063
X2 - Digital Leadership → Y - Digital Learning Environment	0.064
X2 - Digital Leadership → Z - Digital Transformation	0.336
X3 - Digital Literacy → Y - Digital Learning Environment	0.139
X3 - Digital Literacy → Z - Digital Transformation	0.231
Z - Digital Transformation → Y - Digital Learning Environment	0.051

Predictive relevance was assessed with blindfolding (omission distance D = 7). The Q^2 values were 0.375 for both the digital learning environment and digital transformation (Table 8), above zero and above the 0.35 benchmark for large predictive relevance. Because Q^2 is an in-sample measure, out-of-sample predictive performance was evaluated separately with PLSpredict using ten-fold cross-validation. All 12 indicators of the digital learning environment produced lower RMSE values than the naive mean-based benchmark (e.g., Y-1: 0.530 vs. 0.701; Y-3: 0.500 vs. 0.614), indicating high predictive power (Shmueli et al., 2019).

Table 8. Q^2 Test Results

Construct	Q^2 (=1-SSE/SSO)
Y - Digital Learning Environment	0.375
Z - Digital Transformation	0.375

Common method bias was assessed in two ways. Harman's single-factor test on all 51 items extracted ten factors with eigenvalues above one, and the first factor accounted for only 40.05% of the variance, below the 50% threshold. The full collinearity assessment produced VIF values of 1.789 (management support), 2.126 (digital leadership), 2.240 (digital literacy), 2.824 (digital learning environment), and 2.987 (digital transformation), all below 3.3 (Kock, 2015). Common method bias is therefore unlikely to threaten the results.

Robustness was examined by comparing public (n = 109) and private (n = 193) school teachers, with 5,000 bootstrap subsamples per group. Compositional invariance was established and AVE exceeded 0.50 in both groups for all constructs; the digital learning environment showed equal means but unequal variances, so measurement invariance was partial, which is sufficient

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for comparing path coefficients (Henseler et al., 2016). The multigroup analysis found no significant group differences in any direct path (p = 0.061–0.756) or indirect path (p = 0.318–0.577), indicating that the structural relationships hold across school types. Finally, compared with an alternative model without the mediator, including digital transformation raised the R^2 of the digital learning environment from 0.630 to 0.646 ($\Delta R^2 = 0.016$). This modest gain is reported as it is: the position of digital transformation as a conversion mechanism rests primarily on theoretical argument, with the significant indirect effects serving as supporting evidence.

Hypothesis Evaluation

Table 9 shows that all seven direct paths were positive and significant ($p < 0.05$; $t > 1.96$), supporting H1–H7. The strongest path in the model ran from digital leadership to digital transformation (β = 0.420; t = 8.499), followed by digital literacy to digital transformation (β = 0.361; t = 8.949) and digital literacy to the digital learning environment (β = 0.311; t = 5.437). Management support was significantly related to digital transformation (β = 0.186; t = 3.820) and the digital learning environment (β = 0.215; t = 4.743), digital leadership was related to the digital learning environment (β = 0.213; t = 4.598), and digital transformation was related to the digital learning environment (β = 0.226; t = 2.588; p = 0.010). The main driver of school digital transformation is thus the principal's digital leadership, while teachers' digital literacy is most directly linked to the digital learning environment.

Table 9. Bootstrapping Test Results – Path Coefficients

Route	Coefficients	T statistics (|O/S.D|)	P values
X1 - Management Support → Y - Digital Learning Environment	0.215	4.743	0.000
X1 - Management Support → Z - Digital Transformation	0.186	3.820	0.000
X2 - Digital Leadership → Y - Digital Learning Environment	0.213	4.598	0.000
X2 - Digital Leadership → Z - Digital Transformation	0.420	8.499	0.000

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Route	Coefficients	T statistics (|O/S.D|)	P values
X3 - Digital Literacy → Y - Digital Learning Environment	0.311	5.437	0.000
X3 - Digital Literacy → Z - Digital Transformation	0.361	8.949	0.000
Z - Digital Transformation → Y - Digital Learning Environment	0.226	2.588	0.010

Table 10 shows that all three indirect paths through digital transformation were significant, supporting H8–H10: management support (β = 0.042; t = 2.090; p = 0.037; 95% CI [0.008, 0.087]), digital leadership (β = 0.095; t = 2.564; p = 0.011; 95% CI [0.022, 0.167]), and digital literacy (β = 0.082; t = 2.246; p = 0.025; 95% CI [0.017, 0.161]). Because the corresponding direct effects were also significant and of the same positive sign, all three paths represent complementary partial mediation rather than full mediation (Zhao et al., 2010). The VAF was 16.4% for management support (direct 0.215; total 0.257), 30.9% for digital leadership (direct 0.213; total 0.308), and 20.8% for digital literacy (direct 0.311; total 0.393). Digital transformation therefore complements, rather than replaces, the direct contribution of school resources. The largest share flowing through the mechanism belongs to digital leadership, consistent with the argument that a principal's vision cannot become organizational capability without first reorganizing how the school works, whereas teachers' competence can be applied directly in the classroom.

Table 10. Bootstrapping Test Results – Specific Indirect

Route	Coefficients	T statistics (|O/S.D|)	P values
X1 - Management Support → Z - Digital Transformation → Y - Digital Learning Environment	0.042	2.090	0.037
X2 - Digital Leadership → Z - Digital Transformation → Y - Digital Learning Environment	0.095	2.564	0.011

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Route	Coefficients	T statistics (|O/S.D|)	P values
X3 - Digital Literacy → Z - Digital Transformation → Y - Digital Learning Environment	0.082	2.246	0.025

DISCUSSION

The findings indicate that management support, digital leadership, digital literacy, and digital transformation are all significantly related to the digital learning environment, and that digital transformation partially mediates the relationships between the three antecedents and that environment. Viewed through the Resource-Based View (Barney, 1991), the antecedents are ordered according to their theoretical position: digital leadership, a managerial capability, is the strongest driver of digital transformation; digital literacy, a form of digital human capital, has the largest direct relationship with the digital learning environment; and management support, an organizational resource, has the smallest coefficients on both paths. Given the cross-sectional design, these results are interpreted as explanatory associations rather than causal effects.

School management support serves as an institutional enabler by assuring the availability of appropriate policies, infrastructure, and resources to improve the digital learning environment. These findings align with prior literature emphasizing institutional commitment and policy alignment as critical to successful education digitalization (Feng et al., 2025; Alenezi, 2023; Zou et al., 2025). Management support nonetheless showed the smallest coefficients and effect sizes in the model. This does not mean that it is unimportant; rather, it is a necessary but not sufficient condition. Policies, budgets, and facilities are valuable, but any school can assemble them in similar ways, so they are easy to imitate and limited in their capacity to differentiate outcomes (Barney, 1991). Descriptive statistics support this reading: teachers rated the availability of facilities highly (mean = 4.427), whereas digital transformation received the lowest mean score of all constructs (4.167). What schools possess most is resources; what lags most is the process of putting them to use. Management support therefore needs to change form, from procuring devices to supporting the reorganization of work, mentoring, and capacity building. Its significant indirect effect through digital transformation confirms that policies and resources also operate by enabling this reorganization, in line with Alenezi (2023), who emphasizes institutional restructuring and governance as prerequisites for successful educational digitalization.

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In addition, the positive significant influence of digital leadership on digital transformation and digital learning environment, which supports Karakose et al. (2024), Okunlola and Naicker (2025), and Figueroa et al. (2025), emphasizes visionary leadership as a change agent in building digital culture and driving systemic improvement. In this study, the path from digital leadership to digital transformation was the strongest in the model ($\beta = 0.420$; $f^2 = 0.336$), and digital leadership also had the largest share of its effect transmitted through digital transformation (VAF = 30.9%). The Resource-Based View helps explain this pattern: a principal's ability to formulate a digital vision and model digital citizenship is not acquired through procurement but develops through years of leadership experience tied to each school's trajectory, which makes it path dependent and difficult to imitate (Barney, 1991). Dynamic Capabilities theory clarifies how it operates: reading digital needs and articulating a vision reflect sensing, allocating resources and mobilizing staff reflect seizing, and digital transformation itself represents transforming, that is, the reconfiguration of resources, information systems, structures, and work culture (Teece, 2007). Digital leadership thus connects management policies with daily learning practice, ensuring that transformation does not stop at the policy level, and in doing so supports global agendas such as UNESCO Education 2030 and SDG 4 on quality education.

Digital literacy had the largest direct relationship with the digital learning environment ($\beta = 0.311$) and the second-strongest relationship with digital transformation ($\beta = 0.361$). Because the construct was restricted to competence inherent in teachers, excluding school infrastructure and parental support, this finding indicates that teachers' own digital competence, rather than the availability of facilities, is associated with the quality of digital learning delivery. Its moderate VAF (20.8%) suggests that teacher competence works mainly directly in everyday teaching and only partly through organizational reorganization. These results reinforce existing literature (Alghamdi, 2022; Zou et al., 2025; Widowati et al., 2023) that identifies digital literacy as a core competency and foundational skill in 21st-century education. Teachers' ability to access, evaluate, and use digital technology enhances learning quality by making it more personalized, interactive, and inclusive, aligning with the UNESCO Education 2030 agenda and the OECD Future of Education and Skills Framework. Digital literacy encompasses not only technical proficiency with digital devices but also the capacity to integrate technology into innovative pedagogical strategies. Teachers with high digital literacy can design learning experiences tailored to students' needs, such as project-based learning, collaborative platforms, and multimedia integration. This is in line with the view by Zou et al. (2025) which emphasizes that digital literacy is an important

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prerequisite for creating an inclusive learning environment, because digitally literate teachers are better able to accommodate the diverse needs of students, including those with limited access or ability.

This research extends the literature by highlighting digital transformation as a strategic mechanism bridging organizational factors and individual competencies. Digital transformation is more than just implementing new technology; it is a comprehensive process that integrates management policies, visionary leadership, and teachers' digital literacy into a coherent framework. It ensures that management support transcends policy formulation, that digital leadership extends beyond vision articulation, and that digital literacy moves beyond individual skills, connecting these elements to drive tangible improvements in learning quality. This perspective aligns with Tai & Son (2023) and Vuorikari et al. (2022) who describe digital transformation as a mediating mechanism among management support, digital leadership, and digital literacy to establish an adaptive and sustainable digital learning environment. The mediation results nonetheless call for a measured interpretation. All three indirect effects were significant, but they were complementary partial mediations with VAF values of 16.4–30.9%, and including the mediator increased the explained variance of the digital learning environment by only 0.016. Digital transformation therefore complements rather than replaces the direct contribution of school resources: part of the influence of management support, digital leadership, and digital literacy works directly through daily teaching practice, while another part passes through the reorganization of resources, information systems, structures, and school culture. Notably, digital transformation received the lowest mean rating of all constructs, indicating that the process dimension is where schools lag most.

The novelty of this study is a mechanism novelty rather than a novelty of variable combination. It explains how an organizational resource (management support), a managerial capability (digital leadership), and digital human capital (teachers' digital literacy) are converted through a digital transformation mechanism into an organizational capability for digital learning, with digital leadership as the main driver of this conversion. This explanation is summarized as the Digital Learning Capability Pyramid, a three-tier hierarchy with resources and digital human capital at the base, digital transformation as the conversion mechanism in the middle, and the digital learning environment as an organizational capability at the top. The pyramid posits that a higher tier cannot form without the tiers beneath it, and that possessing resources at the base does not automatically produce capability at the top without passing through the middle tier.

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Empirical support for this hierarchy is complementary rather than decisive, given the modest incremental R^2 and VAF values; the claim rests primarily on the Resource-Based View and Dynamic Capabilities theory (Barney, 1991; Teece, 2007), with the mediation results as corroborating evidence. Two further contributions are the reconceptualization of the digital learning environment as an organizational capability rather than a container, facility, or ecosystem, and the refinement of digital literacy as an individual teacher competence separated from infrastructure and environmental support.

The practical implications follow from the ordering of the paths. Because the strongest driver of school digital transformation is the principal's digital leadership while facility provision is already rated highly, strengthening principals' digital leadership warrants higher priority than adding facilities. Schools and education authorities should invest in principals' capacity to set a digital vision, lead change, and build a digital culture; make teachers' digital competence a sustained development priority; and redirect management support from procuring devices toward supporting the reorganization of work, mentoring, and capacity building. These recommendations apply to schools whose digital facilities are already adequate; where facilities remain insufficient, management support is likely to remain the main constraint.

CONCLUSION

This study shows that management support, digital leadership, and digital literacy are positively and significantly related to the digital learning environment, both directly and through digital transformation, with all ten hypotheses supported. Digital leadership is the strongest driver of digital transformation, digital literacy has the largest direct relationship with the digital learning environment, and management support functions as a necessary but not sufficient condition. Digital transformation acts as a complementary partial mediator that converts school resources into digital learning capability, as summarized in the Digital Learning Capability Pyramid. Building digital learning capability therefore depends less on adding facilities than on strengthening the mechanisms, especially leadership and teacher competence, that convert existing resources into the ability to deliver digital learning.

This study has several limitations. Its cross-sectional design precludes verification of temporal order and leaves possible reciprocal relationships, for example between digital leadership and digital transformation, unresolved, so the findings should be read as explanatory rather than causal. All data came from teachers through a single instrument; although the

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common method bias tests did not indicate a serious threat, multi-source data would strengthen validity. Conclusions apply to teachers' perceptions of organizational phenomena rather than to schools as units, because about eight teachers per school did not allow justified aggregation. The non-probability sample limits statistical generalization, power to detect very small effects was limited (0.466), and the Jakarta context, with relatively advanced digital infrastructure, may differ from other regions. Future research should employ longitudinal or panel designs, multilevel analysis with rwg and ICC justification, multi-source data, other regions and educational levels, and qualitative methods to explore dynamics such as cultural resistance and motivation.

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