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A TPACK-BASED MODEL OF DIGITAL PLATFORM UTILIZATION FOR LEARNING EFFECTIVENESS AMONG SENIOR HIGH SCHOOL TEACHERS IN TOMOHON

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ABSTRAK

Pemanfaatan platform digital dalam pembelajaran di sekolah menengah tidak hanya bergantung pada ketersediaan teknologi, tetapi juga pada kemampuan guru mengintegrasikannya dengan pedagogi dan konten pembelajaran. Penelitian ini bertujuan menganalisis hubungan antara *digital platform utilization* (DPU) dan *learning effectiveness* (LE) dengan *TPACK integration* (TPACK-Int) sebagai mekanisme mediasi. Penelitian menggunakan desain kuantitatif eksplanatori dengan pendekatan potong lintang. Data diperoleh melalui kuesioner dari 218 guru SMA di Kota Tomohon, Indonesia, yang dianalisis menggunakan Partial Least Squares Structural Equation Modeling (PLS-SEM). Hasil penelitian menunjukkan bahwa DPU berhubungan positif dengan TPACK-Int dan LE, sedangkan TPACK-Int juga berhubungan positif dengan LE. Hubungan tidak langsung antara DPU dan LE melalui TPACK-Int signifikan, yang menunjukkan bahwa integrasi TPACK merupakan mekanisme penting dalam menghubungkan pemanfaatan platform digital dengan efektivitas pembelajaran. Model menjelaskan 43,4% variasi TPACK-Int dan 60,7% variasi LE. Temuan ini menunjukkan bahwa pengembangan pembelajaran digital perlu diarahkan tidak hanya pada perluasan akses terhadap platform, tetapi juga pada penguatan kemampuan guru dalam mengintegrasikan teknologi, pedagogi, dan konten secara bermakna.

Kata Kunci: *Efektivitas Pembelajaran, Guru SMA, Integrasi TPACK, Pemanfaatan Platform Digital, Pedagogi Digital.*

ABSTRACT

The use of digital platforms in secondary education depends not only on technology availability but also on teachers' ability to integrate technology with pedagogy and instructional content. This study examines the relationship between digital platform utilization (DPU) and learning effectiveness (LE), with TPACK integration (TPACK-Int) as a mediating pathway. Using an explanatory quantitative cross-sectional design, data were collected through a questionnaire from 218 senior high school teachers in Tomohon City, Indonesia, and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results show that DPU is positively associated with TPACK-Int and LE, while TPACK-Int is also positively associated with LE. The indirect relationship between DPU and LE through TPACK-Int is significant, indicating that TPACK integration represents an important mechanism linking digital platform utilization with learning effectiveness. The model explains 43.4% of the variance in TPACK-Int and 60.7% in LE. These findings suggest that digital education initiatives should move beyond platform access toward strengthening teachers' capacity to integrate technology, pedagogy, and content meaningfully.

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Keywords: *Digital Pedagogy, High School Teachers, Learning Effectiveness, Digital Platform Utilization, TPACK Integration.*

INTRODUCTION

Digital platforms do not become educationally effective simply through adoption or frequency of use. Their educational value depends on how teachers connect technological affordances with instructional strategies, learning objectives, and subject-matter requirements. Recent research emphasizes that technology integration is a complex process in which teachers' technological, pedagogical, and content knowledge influences how digital tools are translated into instructional practice (Jibril & Adedokun-Shittu, 2024; Shamim et al., 2024). Digital interventions can also contribute to the development of teachers' TPACK, indicating that technology use becomes educationally meaningful when it is accompanied by appropriate pedagogical and content integration (Abouelenein & Selim, 2024). Thus, the central issue in digital education is not merely whether teachers use digital platforms, but how they integrate these platforms into pedagogically appropriate and content-specific teaching practices.

The Technological Pedagogical Content Knowledge (TPACK) framework provides a relevant perspective for examining this integration because it emphasizes the interaction among technological, pedagogical, and content knowledge. Recent studies demonstrate that TPACK is associated with teachers' self-efficacy, technology integration, and instructional competence (Joshi, 2023; Kapici & Akcay, 2023; Luo & Zou, 2024). TPACK-based training and instructional interventions have also been shown to strengthen teachers' TPACK perceptions, technological proficiency, digital competency, and learning outcomes (Diamah et al., 2022; Mgeladze & Kapanadze, 2025; Nantha et al., 2024; Pasmala et al., 2025; Setyo et al., 2023; Susilawati et al., 2025). These findings indicate that TPACK is relevant not only as a measure of teacher competence but also as a framework for understanding how technological resources can be connected with instructional processes and learning outcomes.

Nevertheless, the existing literature remains divided between studies examining TPACK competence, self-efficacy, and readiness and studies evaluating particular TPACK-based interventions or instructional models. For example, Joshi (2023) focuses on the relationship between TPACK and teacher self-efficacy, whereas other studies emphasize training, lesson planning, or specific learning models as mechanisms for developing TPACK and technology-supported learning (Diamah et al., 2022; Kapici & Akcay, 2023; Mgeladze & Kapanadze, 2025; Pasmala et al., 2025). Research on online teaching likewise highlights the importance of TPACK in connecting technology with pedagogical and content considerations (Luo & Zou, 2024). However, these studies provide relatively limited explanation of how teachers' everyday utilization of digital platforms may be translated into learning effectiveness through TPACK integration. Recent evidence further indicates that techno-pedagogical competence and teachers' readiness may depend on intervening conditions such as self-efficacy, reinforcing the need to examine the processes connecting technology use with instructional practice (Oroh et al., 2025).

In this study, digital platform utilization refers to teachers' purposeful use of digital platforms to support instructional planning, interaction, collaboration, assessment, and learning management. TPACK integration refers to teachers' capacity to align technological affordances with pedagogical strategies and subject-specific content in the teaching process. Learning effectiveness refers to the extent to which technology-integrated instruction supports meaningful engagement, instructional quality, and the achievement of intended learning objectives. This conceptualization positions TPACK integration as an intervening process

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rather than merely an additional teacher competency, consistent with evidence that the application of TPACK depends on how teachers connect technological, pedagogical, and content knowledge within specific instructional contexts (Abouelenein & Selim, 2024; Luo & Zou, 2024).

The issue is particularly relevant to senior high schools in Tomohon, Indonesia, where digital platform use has become part of teachers' instructional practices. Recent evidence from Tomohon shows that teachers' digital platform utilization is influenced by performance expectations and effort expectations, with perceived usefulness emerging as an important factor in platform use (Tiwow et al., 2025). This finding establishes digital platform utilization as an empirical reality in Tomohon but does not explain whether such utilization is translated into effective instructional practice. The broader educational context in Tomohon also highlights the importance of developing educational approaches that respond to changing instructional demands and local conditions (Tiwow et al., 2025). Accordingly, examining teachers in Tomohon provides an opportunity to move beyond technology adoption and investigate how digital platform utilization is connected with learning effectiveness through TPACK integration.

Previous research has provided substantial evidence concerning TPACK competence, technology integration, teacher readiness, and instructional interventions. However, previous studies have mainly examined TPACK as a predictor of teacher competence or learning outcomes, while its role as a mediating mechanism between digital platform utilization and learning effectiveness remains less explicitly examined. Although Diamah et al. (2022), Nantha et al. (2024), and Setyo et al. (2023) demonstrate the relevance of TPACK to teacher competence, digital competency, and learning outcomes, these studies do not specifically position TPACK integration as a mediator in this relationship. The novelty of this study therefore lies in empirically testing TPACK integration as a mediator between digital platform utilization and learning effectiveness among senior high school teachers in Tomohon, thereby examining whether technology use contributes to learning effectiveness through teachers' integration of technology, pedagogy, and content knowledge. This model extends previous TPACK research by examining these constructs within a single mediation framework and provides contextual evidence from Indonesian senior high school teachers.

Building on this framework, digital platform utilization is expected to provide instructional opportunities that may contribute directly to learning effectiveness while also supporting teachers' TPACK integration. TPACK integration is consequently expected to strengthen the connection between technology use and meaningful instructional practice. Accordingly, the study proposes four hypotheses: H1, digital platform utilization positively influences TPACK integration; H2, digital platform utilization positively influences learning effectiveness; H3, TPACK integration positively influences learning effectiveness; and H4, TPACK integration mediates the relationship between digital platform utilization and learning effectiveness. These hypotheses are consistent with prior evidence that technology-supported teaching, TPACK development, and TPACK-based instructional models are associated with improvements in teacher competence and learning-related outcomes (Abouelenein & Selim, 2024; Mgeladze & Kapanadze, 2025; Pasmala et al., 2025; Susilawati et al., 2025). The proposed model therefore shifts the analytical focus from technology utilization alone toward the integrative process through which teachers may translate digital platform affordances into pedagogically meaningful learning practice.

METHOD

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This study employed an explanatory quantitative approach with a non-experimental cross-sectional design. The population comprised 234 senior high school teachers in Tomohon City, North Sulawesi, and total sampling was applied. Data were collected from May to July 2026 through a five-point Likert-scale questionnaire administered via Google Forms. Of 227 returned responses (97.0%), 218 were retained for analysis, representing 96.0% of the returned responses and 93.2% of the population. The remaining nine responses were excluded during data screening because they did not meet the requirements for inclusion in the final dataset. The instrument consisted of 30 items, with 10 items for each construct. Digital platform utilization covered planning, interaction, collaboration, assessment, and learning management and was adapted from Bower (2019). TPACK integration was measured through indicators of teachers' integration of technology, pedagogy, and content, adapted from established TPACK dimensions (Abouelenein & Selim, 2024; Shamim et al., 2024). The adapted items were adjusted to reflect the instructional context of senior high school teachers in Tomohon and reviewed for clarity and contextual relevance before the questionnaire was administered. Learning effectiveness was measured through student engagement, instructional quality, and achievement of learning objectives, adapted from the teaching and cognitive presence dimensions of the Community of Inquiry framework. Because the questionnaire was completed by teachers, learning effectiveness represented teachers' perceptions of learning effectiveness rather than an objective assessment of student achievement. The indicators covered perceived student engagement, the quality of instructional processes, and the extent to which learning objectives were achieved.

Data were analyzed using SmartPLS 4 with Partial Least Squares Structural Equation Modeling (PLS-SEM). The measurement model was evaluated using outer loadings ≥0.70, AVE ≥0.50, Cronbach's alpha and Composite Reliability ≥0.70, and HTMT <0.85. The structural model was assessed using collinearity, path coefficients, R^2, f^2, Q^2, SRMR, and NFI. R^2 values of 0.25, 0.50, and 0.75 were interpreted as weak, moderate, and substantial; f^2 values of 0.02, 0.15, and 0.35 indicated small, medium, and large effects; Q^2 >0 indicated predictive relevance; SRMR <0.08 indicated acceptable fit; and NFI ≥0.90 was considered acceptable as a supplementary fit indicator. Direct and indirect effects were tested using bootstrapping with 5,000 subsamples. The indirect effect was used to determine whether TPACK integration mediated the relationship between digital platform utilization and learning effectiveness. Participation was voluntary, with informed consent obtained before questionnaire completion.

RESULT AND DISCOSSION

Result

Reliability and Convergent Validity

The reliability and convergent validity of the measurement model were examined to determine whether the indicators consistently represented their respective latent constructs. These assessments are important because adequate measurement quality provides a basis for interpreting the subsequent structural model. The evaluation considered internal consistency and the extent to which the indicators converged in measuring the same underlying construct. The results of these assessments are presented in Table 1.

Table 1. Evaluation of Convergent Reliability and Validity

Construct	Cronbach's Alpha	Composite Reliability (ρc)	Average Variance	Number of Items

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			Extracted (AVE)	
DPU	0.943	0.951	0.662	10
TPACK-Int	0.927	0.938	0.603	10
LE	0.934	0.944	0.628	10

The findings indicate that the measurement instruments demonstrate adequate internal consistency and convergent validity across the three constructs. The consistency of the indicators suggests that each measurement block functions coherently in representing its intended construct. The convergent validity evidence further indicates that the indicators share sufficient common variance within their respective constructs. Therefore, the measurement model provides an appropriate foundation for proceeding to the assessment of discriminant validity and the structural model.

Discriminant Validity

Discriminant validity was first assessed using the Heterotrait–Monotrait (HTMT) ratio to examine whether the constructs in the measurement model were empirically distinguishable. The assessment focused on the relationships among digital platform utilization, TPACK integration, and learning effectiveness. An HTMT value below 0.85 was used as the criterion for establishing adequate discriminant validity among the constructs. The results of this assessment are presented in Table 2a, which summarizes the HTMT values and their evaluation against the specified threshold.

Table 2a. Discriminant Validity Evaluation

Evaluation Method	TPACK-Int-DPU	TPACK-Int-LE	DPU-LE	Threshold	Status
HTMT	0.700	0.745	0.764	< 0.85	Achieved

As presented in Table 2a, all HTMT values fall below the specified threshold, indicating that the constructs demonstrate adequate empirical distinctiveness. The observed relationships are sufficiently differentiated to support the measurement of digital platform utilization, TPACK integration, and learning effectiveness as separate constructs. This result indicates that the conceptual relationships among the variables do not result in excessive overlap at the measurement level. The HTMT assessment therefore provides initial evidence supporting the discriminant validity of the measurement model.

To strengthen the assessment of discriminant validity, the Fornell–Larcker criterion was subsequently examined. This procedure compares the square root of AVE for each construct with its correlations with the other constructs in the model. Adequate discriminant validity is indicated when the diagonal value for a construct exceeds its associations with the remaining constructs. The results of the Fornell–Larcker assessment are presented in Table 2b.

Table 2b. Discriminant Validity Evaluation

Construct	DPU	LE	TPACK-Int
DPU	0.814		
LE	0.720	0.792	
TPACK-Int	0.659	0.698	0.777

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As shown in Table 2b, the diagonal values for each construct exceed their respective correlations with the other constructs. This pattern indicates that each construct has a stronger relationship with its own indicators than with the other latent variables in the model. The findings provide additional evidence that digital platform utilization, TPACK integration, and learning effectiveness represent empirically distinguishable constructs. When considered together with the HTMT results in Table 2a, the Fornell–Larcker assessment further supports the discriminant validity of the measurement model.

Indicator Loadings and Multicollinearity

The next assessment focused on the quality of individual indicators and the possibility of collinearity within the measurement blocks. Outer loadings were examined to evaluate how strongly each indicator represents its corresponding latent construct. VIF values were also considered to identify whether excessive linear association among indicators could affect the stability of the measurement estimates. The results of these assessments are summarized in Table 3.

Table 3. Loading Factors and VIF Values

Construct	Number of Indicators	Loading Range	VIF Range
Digital Platform Utilization (DPU)	10	0.795 - 0.827	2.289 - 2.663
TPACK Integration (TPACK-Int)	10	0.743 - 0.815	1.915 - 2.407
Learning Effectiveness (LE)	10	0.755 - 0.815	1.992 - 2.442

The findings indicate that the retained indicators provide adequate representation of their respective constructs. The loading pattern suggests that the indicators contribute meaningfully to the measurement of the latent variables, while the VIF results do not indicate problematic redundancy among indicators. Consequently, there was no empirical basis for removing indicators on the grounds of inadequate loading or excessive collinearity. The measurement blocks can therefore be retained for the subsequent structural model assessment.

Model Fit Indices

The overall model fit was assessed using the Standardized Root Mean Square Residual (SRMR) and the Normed Fit Index (NFI). Given the predictive and variance-based orientation of PLS-SEM, these indices were interpreted as complementary diagnostics rather than as the sole basis for evaluating model adequacy. The assessment used an SRMR value below 0.08 and an NFI value above 0.80 as reference criteria for acceptable model fit (Hair et al., 2019). The results are summarized in Table 4.

Table 4. Structural Model Fit Evaluation

Fit Index	Value	Threshold	Interpretation
SRMR	0.045	< 0.08	Good Fit
NFI	0.892	> 0.80	Acceptable Suitability

The SRMR value of 0.045 is below the specified reference value, indicating a relatively low discrepancy between the observed and model-implied correlations. The NFI value of 0.892 also exceeds the reference criterion of 0.80, indicating acceptable incremental fit relative to the

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null model. Taken together, these indices provide complementary evidence that the proposed model demonstrates an acceptable level of fit. Their interpretation should nevertheless be considered alongside the measurement model, explanatory power, predictive relevance, and structural relationships evaluated in the subsequent analysis.

Figure 1 provides a visual representation of the structural model examined in this study. The model connects digital platform utilization with TPACK integration and learning effectiveness and also illustrates the proposed indirect pathway. The displayed coefficients allow the direction and magnitude of the estimated structural relationships to be viewed within the overall model configuration. The figure therefore serves as a visual complement to the numerical results reported in the subsequent structural model analysis.

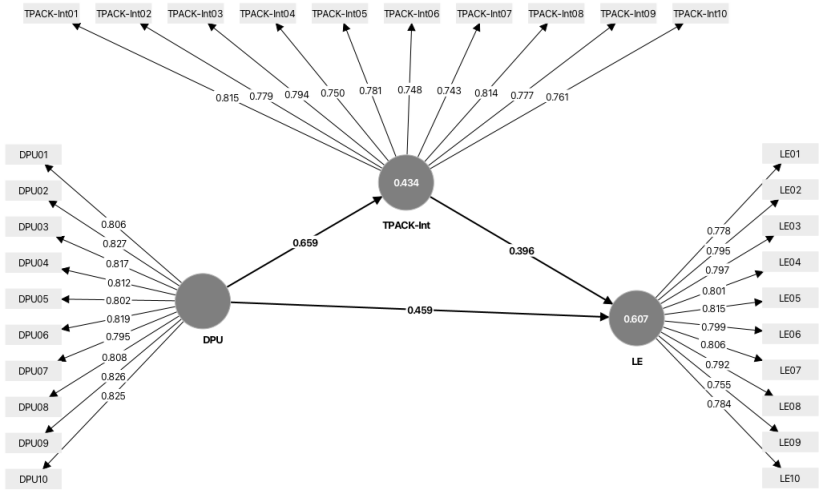

Figure 1. SEM-PLS Model

The structural configuration shown in Figure 1 illustrates the proposed sequence of relationships among the three latent constructs. The model includes both a direct pathway from digital platform utilization to learning effectiveness and an indirect pathway through TPACK integration. This configuration corresponds to the mediation framework specified in the research hypotheses. Statistical support for each pathway is examined more formally through the coefficient of determination, effect-size assessment, and bootstrapping results reported in the following sections.

Coefficient of Determination (R^2) and Predictive Relevance (Q^2)

The explanatory and predictive performance of the structural model was assessed after establishing the adequacy of the measurement model. The coefficient of determination was used to evaluate the extent to which the model accounts for variation in the endogenous constructs. Predictive relevance was examined separately to determine whether the model provides meaningful predictive information for those constructs. The results of these complementary assessments are presented in Table 5.

Table 5. Evaluation of Explanatory and Predictive Performance

Endogenous Constructs	R^2	Q^2
TPACK Integration (TPACK-Int)	0.434	0.257
Learning Effectiveness (LE)	0.607	0.373

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The findings indicate that the structural model provides meaningful explanatory capability for both endogenous constructs. The model accounts for a greater proportion of variation in learning effectiveness than in TPACK integration, indicating that the combination of predictors provides broader explanatory coverage for the outcome construct. The positive predictive-relevance results further indicate that the model possesses predictive usefulness within the assessed framework. Nevertheless, the unexplained variance indicates that additional factors beyond those specified in the model may contribute to the observed outcomes.

Effect Size (f^2)

Beyond statistical significance and explained variance, the analysis examined effect size to determine the relative contribution of individual predictors within the structural model. This assessment helps distinguish relationships that are statistically supported from those that make comparatively greater or smaller contributions to the explained variance. The interpretation of effect size is particularly useful for evaluating the substantive importance of the proposed paths. The resulting effect-size estimates are presented in Table 6.

Table 6. Effect Size Evaluation

Path	f^2	Effect Size
Digital Platform Utilization (DPU) → TPACK Integration (TPACK-Int)	0.767	Large
Digital Platform Utilization (DPU) → Learning Effectiveness (LE)	0.303	Medium
TPACK Integration (TPACK-Int) → Learning Effectiveness (LE)	0.225	Medium

The effect-size assessment indicates that the structural paths do not contribute equally to the model. The relationship involving TPACK integration as an endogenous construct shows the strongest relative contribution, whereas the two predictors of learning effectiveness provide more moderate contributions. This pattern suggests that the role of digital platform utilization is particularly prominent in explaining variation in TPACK integration within the specified model. However, effect size reflects relative contribution within the model and should not be interpreted independently of the path estimates and statistical inference.

Hypothesis Testing and Structural Path Analysis

The structural hypotheses were subsequently evaluated using bootstrapping to determine whether the proposed relationships were statistically supported. The analysis considered the direction and magnitude of each estimated path together with its statistical evidence. The direct relationships were examined first, followed by the indirect relationship involving TPACK integration as the proposed mediator. The results of the hypothesis testing are presented in Table 7.

Table 7. Direct Path Analysis Results

Hypothesis	Path	β	t-value	p-value	Decision
H1	DPU -> TPACK-Int	0.659	17.879	< 0.001	Supported
H2	DPU -> LE	0.459	8.237	< 0.001	Supported
H3	TPACK-Int -> LE	0.396	7.264	< 0.001	Supported
H4	DPU -> TPACK-Int -> LE	0.261	6.867	< 0.001	Supported

The hypothesis testing provides consistent empirical support for the structural relationships specified in the proposed model. The findings indicate that digital platform

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utilization is associated with both TPACK integration and learning effectiveness, while TPACK integration is also associated with learning effectiveness. The indirect pathway further indicates that TPACK integration represents a relevant intermediary mechanism in the relationship between digital platform utilization and learning effectiveness. Because the study employed a cross-sectional and non-experimental design, these findings should be interpreted as statistical associations within the observed model rather than as evidence of causal relationships.

Discussion

The findings suggest that the educational value of digital platforms depends less on their availability than on how teachers integrate them into instructional practice. The strongest relationship between Digital Platform Utilization (DPU) and TPACK Integration (TPACK-Int) indicates that technology use is closely associated with teachers' ability to connect technological resources with pedagogical strategies and content requirements. This finding is consistent with recent evidence that TPACK represents an integrative knowledge structure through which teachers translate technological affordances into contextually appropriate instructional decisions (Jibril & Adedokun-Shittu, 2024; Luo & Zou, 2024; Shamim et al., 2024). Empirical research further shows that digital interventions, lesson planning, and TPACK-oriented training can strengthen teachers' TPACK development and perceptions, although such development depends on how technology is connected with instructional practice rather than on exposure to technology alone (Abouelenein & Selim, 2024; Diamah et al., 2022; Kapici & Akcay, 2023). This interpretation is also supported by recent systematic reviews emphasizing TPACK as a process of knowledge integration rather than a simple accumulation of technological, pedagogical, and content knowledge (Fabian et al., 2024; Jiménez Sierra et al., 2023).

The strong DPU–TPACK relationship therefore suggests that digital platform utilization may provide teachers with repeated opportunities to enact integrated technological, pedagogical, and content knowledge. This interpretation does not imply that platform use automatically develops TPACK, because the process remains dependent on teachers' professional knowledge, instructional experience, and contextual conditions. Research involving in-service secondary teachers indicates that TPACK development and technology integration are shaped by professional development, teaching experience, and the characteristics of the instructional context (Guzmán González & Vesga Bravo, 2024). Similarly, Wang and Zhao (2021) showed that ICT-related support and self-efficacy are connected with TPACK development, while Oroh et al. (2025) found that self-efficacy conditions the relationship between techno-pedagogical competence and teacher readiness. The present finding therefore extends previous research by showing that, among senior high school teachers in Tomohon, everyday utilization of digital platforms is strongly associated with the enactment of integrated technological, pedagogical, and content knowledge within the proposed model.

The model explains a meaningful proportion of variance in TPACK-Int, but the remaining unexplained variance indicates that digital platform utilization is not the sole condition associated with integrated teacher knowledge. Other factors may include professional learning, institutional support, digital infrastructure, teaching experience, subject-specific pedagogical demands, and collaborative professional practices. This interpretation is consistent with the literature showing that technology integration is influenced by both teacher-level and contextual conditions (Wohlfart & Wagner, 2023; Wang & Lee, 2024). The systematic review by Joshi (2023) also demonstrates that TPACK is closely related to teacher self-efficacy, while evidence

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from TPACK-based interventions indicates that structured professional learning can facilitate the development of technology-related pedagogical knowledge (Diamah et al., 2022; Fabian et al., 2024). Thus, the present findings should be interpreted as evidence of the importance of digital platform utilization within a broader configuration of factors rather than as evidence that technology use alone determines TPACK integration.

The positive relationship between DPU and Learning Effectiveness (LE) further indicates that digital platform utilization is associated with more favorable instructional effectiveness in the present sample. This finding is broadly consistent with empirical studies showing that technology-supported and TPACK-based learning approaches can contribute to learning-related outcomes, digital competency, ICT literacy, and critical thinking when technology is integrated into appropriate instructional processes (Mgeladze & Kapanadze, 2025; Nantha et al., 2024; Pasmala et al., 2025; Setyo et al., 2023). Susilawati et al. (2025) similarly reported positive learning outcomes from a TPACK-based contextual teaching and learning model. However, the present finding should not be interpreted as evidence of technological determinism. The educational contribution of digital platforms is more plausibly related to how teachers use platform affordances to organize interaction, collaboration, assessment, learning management, and other instructional activities. This interpretation is compatible with evidence that effective ICT-based teaching depends on teachers' capacity to construct meaningful classroom interaction through TPACK-informed practice (Shamim et al., 2024).

The positive association between TPACK-Int and LE provides further support for the importance of integrated teacher knowledge in technology-supported instruction. Rather than treating technological competence as an independent technical skill, the finding indicates that the educational value of technology is closely related to teachers' ability to coordinate technological choices with pedagogical strategies and subject content. This interpretation is supported by research demonstrating that TPACK-based instructional models can enhance technological proficiency, digital competency, and learning outcomes (Mgeladze & Kapanadze, 2025; Pasmala et al., 2025; Setyo et al., 2023; Susilawati et al., 2025). Reviews of TPACK research likewise emphasize the importance of integrating technology with pedagogy and content rather than evaluating technology use in isolation (Luo & Zou, 2024; Wang & Lee, 2024). The present result therefore strengthens the argument that learning effectiveness is more meaningfully related to the quality of technology integration than to the mere presence or frequency of digital technology use.

The significant indirect relationship through TPACK-Int provides the main theoretical contribution of the model. The mediation pattern indicates that the relationship between DPU and LE operates not only through the practical use of digital platforms but also through teachers' integration of technological, pedagogical, and content knowledge. This finding complements previous intervention-based research showing that TPACK-oriented training and digital interventions can strengthen teachers' capacity to integrate technology into instructional practice (Abouelenein & Selim, 2024; Diamah et al., 2022; Fabian et al., 2024). It also extends studies that have primarily examined TPACK competence, self-efficacy, readiness, or specific instructional interventions by positioning TPACK integration as an intermediary construct linking platform utilization with learning effectiveness. The partial mediation pattern suggests that TPACK-Int is an important explanatory pathway but does not fully account for the relationship between DPU and LE. Because the study uses a cross-sectional and non-experimental design, however, this mediation should be interpreted as a statistically supported indirect association rather than definitive evidence of a temporal or causal mechanism.

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The relative contribution of the structural paths also provides an important interpretation of the model. The stronger contribution of DPU to TPACK-Int than to LE suggests that digital platform utilization is more closely associated with teachers' professional enactment of integrated knowledge than with the broader educational outcome itself. Learning effectiveness is inherently more distal and may depend on student characteristics, instructional design, classroom conditions, school support, subject complexity, and other factors not included in the present model. This interpretation is consistent with the broader literature emphasizing that technology integration is shaped by multiple teacher and contextual conditions (Guzmán González & Vesga Bravo, 2024; Wang & Lee, 2024; Wohlfart & Wagner, 2023). The positive predictive relevance of both endogenous constructs further supports the usefulness of the proposed model, while the remaining unexplained variance indicates that future models should incorporate additional contextual and individual-level predictors. Accordingly, the findings support a *platform-to-pedagogy integration pathway* rather than a simple technology-to-effectiveness relationship.

The novelty of this study lies in empirically positioning TPACK integration as a mediating mechanism between everyday digital platform utilization and learning effectiveness among senior high school teachers in Tomohon. This extends previous research that has predominantly examined TPACK self-efficacy, professional development, technology integration, or particular TPACK-based instructional interventions (Abouelenein & Selim, 2024; Joshi, 2023; Kapici & Akcay, 2023; Jiménez Sierra et al., 2023). The context is also relevant because previous evidence from Tomohon has documented factors associated with teachers' digital platform use, while the present study moves beyond platform adoption to examine how utilization is connected with instructional effectiveness through TPACK integration (Tiwow et al., 2025). Practically, the findings suggest that professional development should not focus exclusively on teaching teachers how to operate digital platforms but should place platform use within concrete pedagogical problems, such as representing difficult content, facilitating interaction, managing collaboration, monitoring learning, and aligning digital activities with instructional objectives. This approach is consistent with evidence that teacher development, collaborative learning, and contextualized TPACK practices can strengthen technology integration (Diamah et al., 2022; Mgeladze & Kapanadze, 2025; Nantha et al., 2024). Nevertheless, the findings remain bounded by the cross-sectional design, self-reported measures, and the specific institutional context of senior high schools in Tomohon. Future studies should therefore consider longitudinal designs, classroom observations, student-level learning outcomes, and contextual variables such as institutional support, digital infrastructure, professional learning communities, and subject-specific pedagogical demands.

CONCLUSION

This study concludes that digital platform utilization (DPU) is associated with learning effectiveness (LE) both directly and through TPACK integration (TPACK-Int). The findings indicate that TPACK-Int represents an important mechanism linking digital platform use with learning effectiveness, suggesting that the educational contribution of digital platforms depends not only on their availability or use but also on teachers' ability to integrate technology with appropriate pedagogy and subject content. This finding highlights the distinction between technological access and pedagogically meaningful technology integration, positioning TPACK-Int as a key component in translating digital platform use into more effective learning practices.

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Theoretically, the study extends understanding of digital technology integration by positioning TPACK-Int as an important explanatory pathway between platform utilization and learning effectiveness. Practically, it suggests that investments in digital platforms should be accompanied by professional development that strengthens teachers' integrative TPACK capacity, particularly in aligning technology with instructional strategies and subject content. The findings should be interpreted within the limitations of the cross-sectional design, self-reported measures, and geographically limited sample. Future research should employ longitudinal or experimental designs, involve broader educational contexts, and incorporate objective indicators of learning outcomes to examine the temporal development of TPACK integration and its relationship with learning effectiveness more rigorously.

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