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Research Article

EVALUATING TEACHER DIGITAL COMPETENCE AND ADAPTIVE PEDAGOGY IN POST-PANDEMIC HYBRID LEARNING MODELS: A STRUCTURAL EQUATION MODELING APPROACH

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Abstract

The transition toward post-pandemic hybrid learning has increased the demand for teachers' digital competence and adaptive pedagogical practices. Despite technological advancements, challenges persist in integrating digital skills with instructional flexibility to ensure effective learning experiences. This study aims to examine the structural relationships among teacher digital competence, adaptive pedagogy, and hybrid learning effectiveness, emphasizing the mediating role of adaptive pedagogy. A quantitative research design employing Structural Equation Modeling with Partial Least Squares (PLS-SEM) is proposed to investigate relationships among the research constructs. Data are collected through structured questionnaires measuring digital competence, pedagogical adaptability, and perceived hybrid learning effectiveness. The proposed structural model suggests that digital competence may contribute directly to hybrid learning effectiveness and indirectly through adaptive pedagogy. Pedagogical adaptability is hypothesized to facilitate differentiated instruction, flexible learning strategies, and responsiveness to students' diverse learning needs. These relationships require empirical testing to establish their statistical significance and explanatory power. Integrating digital competence with adaptive pedagogical practices offers a promising framework for strengthening post-pandemic hybrid education. The study provides a conceptual foundation for teacher professional development, instructional innovation, and future empirical evaluation of technology-supported teaching effectiveness across diverse educational contexts and settings.

Keywords: Teacher Digital Competence; Adaptive Pedagogy; Hybrid Learning; Post-Pandemic Education; Structural Equation Modeling.

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INTRODUCTION

The global transformation of education following the COVID-19 pandemic has fundamentally reshaped teaching practices, instructional environments, and expectations regarding teachers' professional competencies (Chiu et al., 2025). Educational institutions have increasingly incorporated digital technologies into conventional classroom practices, accelerating the adoption of hybrid learning models that combine face-to-face instruction with online educational activities (Kiryakova & Kozhuharova, 2024). This transition reflects a broader transformation in educational delivery, where technological integration is no longer viewed exclusively as an emergency response but as an increasingly important component of instructional innovation.

Hybrid learning provides opportunities to improve educational accessibility, instructional flexibility, and student engagement through the integration of synchronous and asynchronous learning experiences (Tang, 2024). The effectiveness of these models, however, depends substantially on teachers' abilities to select appropriate technologies, organize meaningful learning activities, and respond to students' diverse educational needs (Haşlaman et al., 2024). The post-pandemic educational landscape consequently requires a deeper understanding of how teacher digital competence interacts with adaptive pedagogical practices to support effective learning environments (Wu et al., 2025). This transformation establishes the importance of examining teacher-related factors that influence the sustainability and quality of hybrid learning implementation.

Teacher digital competence represents a multidimensional professional capability involving the knowledge, skills, attitudes, and pedagogical judgment required to integrate digital technologies effectively into educational practices (E. D. Zhang & Yu, 2025). The European Framework for the Digital Competence of Educators (DigCompEdu), developed by Redecker (2017), identifies six interconnected competency areas encompassing professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence (Mahmoudi-Dehaki & Nasr-Esfahani, 2025). This framework emphasizes that digital competence extends beyond basic technological proficiency to include the pedagogical application of digital resources and the ability to create inclusive, engaging, and meaningful learning experiences.

Teachers with stronger digital competencies may be better positioned to design technology-supported instruction, facilitate collaborative learning, monitor student progress, and provide timely feedback (Hu et al., 2025). Digital competence, however, should not be assumed to guarantee instructional effectiveness because the educational value of technology depends on how it is incorporated into teaching strategies (Johnson et al., 2024). The relationship between teachers' technological capabilities and their instructional practices therefore requires systematic investigation, particularly in hybrid learning environments that demand continuous coordination between physical and digital learning spaces.

Adaptive pedagogy has emerged as an important educational approach for addressing differences in students' learning readiness, abilities, preferences, engagement, and access to educational resources (Rahimi, 2025). This approach emphasizes teachers' capacity to modify instructional strategies, learning materials, assessment procedures, and classroom interactions according to students' emerging educational needs (Hoang et al., 2025). Post-pandemic hybrid learning environments present distinctive challenges because teachers must simultaneously accommodate variations in digital access, independent learning skills, academic performance, and participation across online and face-to-face settings.

Adaptive pedagogy provides a conceptual foundation for responding to these challenges through flexible instructional design, differentiated learning activities, formative assessment, and individualized feedback. Digital technologies can support such practices by providing learning analytics, interactive educational resources, and multiple pathways for student participation (Wijayanti et al., 2024). The successful implementation of adaptive pedagogy

nevertheless requires teachers to interpret learning evidence, exercise professional judgment, and make appropriate instructional adjustments (Hoel & Jernes, 2024). The interaction between digital competence and pedagogical adaptability consequently represents an important area of investigation for understanding the conditions associated with effective post-pandemic hybrid learning.

The increasing availability of digital technologies in educational institutions does not necessarily ensure that teachers can employ these resources to create effective learning experiences (Baimukhambetova et al., 2025). Teachers may demonstrate confidence in using digital applications, learning management systems, and online communication platforms while experiencing difficulties in translating technological knowledge into differentiated instructional strategies. This discrepancy highlights the distinction between technological proficiency and pedagogically meaningful technology integration (Zubtsova et al., 2024). Research by Claro et al. (2024), which systematically reviewed quantitative studies of in-service teachers' digital competence, identified inconsistencies in how digital competence is operationalized and measured, including comparatively limited emphasis on teachers' abilities to develop students' activities and skills.

The implementation of adaptive pedagogy within hybrid learning models presents challenges related to instructional planning, student engagement, digital accessibility, assessment flexibility, and the coordination of multiple learning environments (Fredy et al., 2026). Teachers must make pedagogical decisions based on students' learning progress while navigating differences between classroom-based interaction and digitally mediated participation (Gonscherowski & Rott, 2026). These demands may become particularly significant when learners demonstrate uneven technological access, different levels of self-regulation, or varying abilities to participate in independent learning activities.

Adaptive teaching requires educators to recognize individual learning needs and modify instructional practices without compromising curriculum coherence or academic expectations (Denoni Buján & Cebollero Salinas, 2025). The practical difficulty lies in determining whether teachers possess the digital and pedagogical competencies necessary to implement these adjustments consistently (Keicher et al., 2024). The availability of educational technologies may facilitate adaptive instruction, but technological resources alone cannot establish whether meaningful pedagogical adaptation occurs (Huertas-Abril & Anh Hà, 2024). Understanding how teachers' digital competencies relate to their adaptive teaching capabilities is therefore essential for identifying professional development priorities and improving instructional quality in hybrid educational settings.

The relationships among teacher digital competence, adaptive pedagogy, and hybrid learning effectiveness remain an important empirical concern because these constructs represent distinct yet potentially interconnected dimensions of instructional quality (Yan & Chen, 2026). Digital competence refers to teachers' technological and pedagogical capabilities, adaptive pedagogy concerns their responsiveness to learners' needs, and hybrid learning effectiveness reflects the extent to which intended educational objectives are achieved within combined instructional environments (Tomczyk et al., 2024). Existing educational discussions frequently emphasize the importance of these dimensions, but establishing their structural relationships requires explicit theoretical models and valid empirical measurements.

A central question is whether digital competence has a direct association with hybrid learning effectiveness or whether its relationship with educational outcomes is partially explained by adaptive pedagogy (Ma'arif & Arif, 2026). The possibility of indirect relationships introduces important considerations regarding how teacher competencies translate into instructional practices (Frolova et al., 2025). Structural Equation Modeling (SEM) provides an analytical approach for investigating these relationships simultaneously while accounting for measurement error in latent constructs, subject to appropriate model specification and statistical assumptions.

This study aims to evaluate the relationship between teacher digital competence and perceived hybrid learning effectiveness in post-pandemic educational environments (Zainal et al., 2025). The investigation focuses on determining whether teachers' capabilities in digital resource management, technology-supported instruction, digital assessment, and online learning facilitation are positively associated with the perceived quality of hybrid learning implementation (Basilotta-Gómez-Pablos et al., 2025). Teacher digital competence is conceptualized as a multidimensional construct representing the integration of technological proficiency and pedagogical judgment.

Hybrid learning effectiveness is examined through indicators associated with instructional organization, learner engagement, assessment responsiveness, and perceived achievement of learning objectives (Hetmanenko, 2024). The research seeks to establish the magnitude and statistical significance of the structural relationship between these constructs using an appropriate SEM approach (Ambros et al., 2024). The results are expected to provide empirical evidence concerning the explanatory contribution of teacher digital competence to hybrid learning effectiveness (Manto et al., 2025). Such evidence may inform the development of professional competency frameworks and educational strategies designed to strengthen technology-supported teaching practices.

The second objective is to investigate the relationship between adaptive pedagogy and hybrid learning effectiveness while examining the association between teacher digital competence and pedagogical adaptability (L. Zhang, 2024). Adaptive pedagogy is operationalized through teachers' reported capacity to differentiate instructional activities, modify teaching strategies, provide individualized learning support, and use assessment information to respond to students' needs (Oben & Hui, 2025). The study seeks to determine whether higher levels of digital competence are associated with stronger adaptive pedagogical practices and whether such practices are related to more favorable evaluations of hybrid learning effectiveness.

Particular attention is directed toward the educational processes through which technological resources may support flexible instruction and responsive teaching decisions (Li et al., 2024). The investigation also considers the possibility that teachers with similar digital competency levels may demonstrate different degrees of pedagogical adaptability (Hamzaoui et al., 2024). These relationships are examined within a structural framework to clarify the distinct contributions of digital competence and adaptive pedagogy to the implementation of post-pandemic hybrid learning.

The third objective is to test the potential mediating role of adaptive pedagogy in the relationship between teacher digital competence and hybrid learning effectiveness (Taghizadeh et al., 2024). The proposed model specifies teacher digital competence as an exogenous construct, adaptive pedagogy as a mediating construct, and hybrid learning effectiveness as an endogenous construct (Pozza et al., 2025). Structural Equation Modeling enables the simultaneous estimation of direct and indirect relationships among these variables, allowing the research to evaluate whether adaptive pedagogy statistically accounts for part of the association between digital competence and perceived hybrid learning effectiveness.

The analytical procedures include assessing construct reliability, convergent validity, discriminant validity, structural path coefficients, explanatory power, and the statistical significance of indirect effects (Kennedy et al., 2025). The study aims to establish an empirically supported model that can inform teacher professional development and educational decision-making (Cempellin & Crawford, 2024). The interpretation of mediation remains associational unless the research design provides sufficient evidence to support causal conclusions.

Existing research has established teacher digital competence as an important component of technology-supported educational practice, but conceptual and measurement challenges remain. Claro et al. (2024) identified a lack of consensus regarding the operationalization of

teacher digital competence, contributing to differences in measurement approaches and limiting comparability across studies (Agnew & Ó Grádaigh, 2026). The review also indicated that assessments frequently focus on the use of technology for instructional planning and teaching rather than the broader development of learner-centered educational activities.

These findings demonstrate the need to connect digital competence with clearly defined pedagogical processes and instructional outcomes (Malak et al., 2026). The present study addresses this concern by examining digital competence alongside adaptive pedagogy and perceived hybrid learning effectiveness within an integrated measurement and structural model (Karmakar et al., 2026). Its contribution lies in evaluating how the constructs relate rather than treating teacher digital competence solely as an independent professional characteristic.

Previous quantitative research has examined several factors influencing teachers' technology integration, including attitudes, self-efficacy, digital competence, and institutional support. A 2024 study published in Heliyon investigated 680 teachers in China using Partial Least Squares Structural Equation Modeling and identified significant relationships involving teachers' attitudes, self-efficacy, digital competence, and ICT integration (Kameswaran et al., 2026). Another study involving 425 preservice English teachers employed SEM to investigate relationships among digital competence, ICT self-efficacy, collegial collaboration, and infrastructural support.

These studies provide useful evidence regarding the psychological and organizational antecedents of digital competence and technology integration (Villa, 2026). Their analytical models, however, do not directly establish the mediating role of adaptive pedagogy between teacher digital competence and perceived hybrid learning effectiveness (Habibi, 2026). The present investigation focuses on this specific structural relationship, examining adaptive pedagogy as a potential mechanism through which teachers' digital capabilities are associated with educational effectiveness (Çukurbaşı Çalışır et al., 2026). The proposed model therefore extends existing technology integration research toward the pedagogical responsiveness required in hybrid learning environments.

Research concerning technology-supported education has frequently been shaped by the extraordinary conditions associated with emergency remote teaching during the COVID-19 pandemic (Piyasena et al., 2026). The educational requirements of sustained post-pandemic hybrid learning differ because teachers must coordinate established face-to-face practices with digital instructional activities over longer implementation periods (Lobalsamo & Segreti, 2024). A recent systematic review of teacher resilience and adaptation in digital teaching contexts identified the need for greater attention to routine post-emergency educational environments, context-sensitive research designs, and stronger investigations of relationships among professional capabilities, pedagogical adaptation, and educational outcomes.

The present study responds to this methodological and contextual need by proposing an SEM-based investigation of teacher digital competence, adaptive pedagogy, and hybrid learning effectiveness in a post-pandemic setting (Maltha Kharisma, 2026). Its contribution does not derive from the use of SEM alone, which is already established in educational research, but from the specification and testing of a theoretically coherent structural model addressing the relationship between technological capability and adaptive instructional practice.

The principal conceptual novelty of this study lies in positioning adaptive pedagogy as an explanatory construct linking teacher digital competence with perceived hybrid learning effectiveness (Pradipta et al., 2026). Existing competency frameworks provide a substantial foundation for understanding teachers' technological capabilities, while research on adaptive teaching emphasizes the importance of responding to learner diversity through flexible instructional decisions. The proposed structural model integrates these perspectives to examine whether digital competence is associated with effective hybrid learning partly through teachers' pedagogical adaptability.

This conceptual integration distinguishes technological capability from its instructional application and recognizes that possessing digital skills does not necessarily guarantee responsive teaching practices (Krumsvik & Slettvoll, 2026). The framework contributes to educational technology research by emphasizing the potential mechanism through which technological competencies may be translated into pedagogical responsiveness. Its novelty must be evaluated against the relevant literature and the empirical performance of the proposed model rather than assumed solely because the constructs are combined.

The methodological contribution of this research involves the simultaneous evaluation of direct and indirect relationships among teacher digital competence, adaptive pedagogy, and hybrid learning effectiveness using Structural Equation Modeling (Shtefan et al., 2025). The proposed approach allows the assessment of latent constructs through multiple indicators while evaluating the extent to which the hypothesized structural relationships are supported by empirical data. Particular attention is directed toward the mediating role of adaptive pedagogy, which provides a more detailed explanation of the relationship between teachers' technological capabilities and their perceptions of hybrid learning effectiveness than a simple bivariate association.

Measurement model assessment is essential for ensuring that the constructs represent conceptually distinct educational dimensions. Structural model evaluation enables the examination of path coefficients, explained variance, effect sizes, and indirect associations (Zhu et al., 2026). The methodological value of this approach lies in the integration of construct validation and hypothesis testing within a coherent analytical framework, rather than in claiming that SEM itself represents a new research method.

The significance of this study extends to educational theory, teacher professional development, and institutional strategies for sustaining effective post-pandemic hybrid learning. Theoretically, the research seeks to clarify how digital competence and adaptive pedagogy are associated with instructional effectiveness within technology-supported educational environments. Pedagogically, the proposed model emphasizes that teachers require both technological capabilities and the professional judgment necessary to adapt learning experiences to students' diverse needs (Lee et al., 2026). Institutionally, the findings may inform the development of targeted professional learning programs that integrate digital resource management, differentiated instruction, formative assessment, and flexible instructional planning.

The research also provides a potential basis for evaluating whether teacher development initiatives should focus primarily on technical competencies or incorporate broader adaptive pedagogical capabilities. Its contribution to educational policy depends on the quality of empirical evidence obtained and the extent to which the proposed relationships remain consistent across relevant educational contexts. The study ultimately seeks to advance understanding of the conditions associated with effective hybrid learning by examining the interconnected roles of teacher digital competence and adaptive pedagogical practice.

RESEARCH METHOD

Research Design

This study employs a quantitative research approach using an explanatory research design to investigate the structural relationships among teacher digital competence, adaptive pedagogy, and hybrid learning effectiveness in post-pandemic educational environments. A cross-sectional survey design is proposed to collect standardized data from teachers who have experience implementing hybrid learning models (Georgopoulou et al., 2026). The research framework comprises three latent constructs: Teacher Digital Competence (TDC) as the independent variable, Adaptive Pedagogy (AP) as the mediating variable, and Hybrid Learning Effectiveness (HLE) as the dependent variable.

The study applies Partial Least Squares Structural Equation Modeling (PLS-SEM) to examine the direct and indirect relationships among these variables, positioning adaptive pedagogy as a mediating variable to determine whether teachers' digital competence is indirectly associated with hybrid learning effectiveness through pedagogical adaptability. PLS-SEM is selected because it supports the simultaneous examination of measurement properties and theoretically specified structural relationships involving multiple latent constructs, particularly when the research emphasizes explained variance and prediction. Although the cross-sectional design allows the identification of statistical associations, it does not independently establish causal relationships among the investigated variables.

Research Target/Subject

The target population consists of teachers employed in educational institutions that have implemented hybrid learning models during the post-pandemic period. Eligible participants include teachers who have conducted both face-to-face and digitally supported instructional activities, possess direct experience using educational technologies to facilitate learning, and have at least one academic semester of experience implementing hybrid learning. Teachers who have no practical experience with hybrid instructional activities are excluded from the study.

The proposed study employs a stratified sampling strategy, where a sufficiently comprehensive institutional sampling frame is available, to ensure representation across educational levels, teaching experience, institutional characteristics, and geographical locations. A minimum sample of approximately 250–300 teachers is proposed as an initial recruitment target, subject to a formal statistical power analysis based on anticipated effect sizes, desired statistical power, significance level, and structural model complexity. Sample size determination also considers mediation analysis requirements, potential nonresponse, and the stability of parameter estimates, while collecting demographic information such as gender, age, educational qualifications, teaching experience, institutional type, and technology utilization frequency.

Research Procedure

The research procedures consist of five sequential stages: instrument development, preliminary validation, participant recruitment and data collection, statistical analysis, and interpretation of findings. The initial stage involves reviewing relevant literature, establishing the conceptual model, defining research constructs, and developing measurement indicators based on existing theoretical frameworks. The validation stage includes expert evaluation and pilot testing involving approximately 30–50 teachers who are not included in the main sample to determine the clarity, relevance, and preliminary reliability of questionnaire items.

Institutional research permissions and ethical approval are obtained before recruitment and data collection, and participants receive information regarding study objectives, voluntary participation, confidentiality, and data protection before providing informed consent. The main survey is administered electronically using a secure questionnaire platform, with eligibility screening and appropriate measures to minimize duplicate responses and incomplete submissions. The final stage involves interpreting the findings in relation to the research objectives, theoretical framework, and existing empirical literature, with particular attention to implications for teacher professional development and hybrid learning implementation.

Instruments, and Data Collection Techniques

Data are collected using a structured questionnaire comprising demographic information and three multidimensional measurement constructs: Teacher Digital Competence (TDC), Adaptive Pedagogy (AP), and Hybrid Learning Effectiveness (HLE). The instrument uses a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) to measure participants' perceptions of their professional competencies and instructional practices. The

questionnaire is subjected to expert judgment to assess content relevance, conceptual clarity, and alignment between indicators and their respective constructs.

Teacher Digital Competence is operationalized through indicators adapted from the European Framework for the Digital Competence of Educators (DigCompEdu), including digital resource management, technology-supported teaching, digital assessment, learner empowerment, and professional digital engagement. Adaptive Pedagogy is measured through instructional flexibility, differentiated teaching strategies, formative assessment responsiveness, individualized learning support, and instructional modification. Hybrid Learning Effectiveness is assessed through perceived instructional effectiveness, learner engagement, learning accessibility, assessment effectiveness, and the achievement of intended instructional objectives.

Data Analysis Technique

Data screening includes examining missing values, response patterns, potential outliers, and possible sources of common method bias prior to structural modeling. Measurement quality is initially evaluated through indicator loadings, Cronbach's alpha, composite reliability, average variance extracted (AVE), and the heterotrait–monotrait ratio (HTMT). Reflective constructs are expected to demonstrate satisfactory internal consistency, with reliability coefficients generally between 0.70 and 0.95, AVE values of at least 0.50, and HTMT values below the theoretically justified discriminant validity threshold, retaining or revising indicators based on statistical evidence and theoretical relevance.

Statistical analysis is conducted using PLS-SEM software, such as SmartPLS, through a two-stage evaluation process consisting of measurement model assessment and structural model evaluation. The structural model is evaluated using collinearity statistics, standardized path coefficients, coefficients of determination (R^2), effect sizes (f^2), and predictive performance where appropriate. Bootstrapping with 5,000 or more resamples is employed to estimate confidence intervals and assess the statistical significance of direct and indirect effects at a significance level of 0.05, specifically evaluating the mediating role of Adaptive Pedagogy by examining the bootstrapped indirect effect linking Teacher Digital Competence to Hybrid Learning Effectiveness.

RESULTS AND DISCUSSION

The descriptive analysis focuses on the demographic characteristics, professional backgrounds, and digital teaching experiences of teachers participating in post-pandemic hybrid learning environments. The dataset is intended to represent teachers who have implemented both face-to-face and digitally mediated instruction in their educational institutions. Participants are classified according to gender, age, educational qualifications, teaching experience, institutional characteristics, and frequency of educational technology utilization. These characteristics provide contextual information for understanding variations in teacher digital competence, adaptive pedagogical practices, and perceived hybrid learning effectiveness. Descriptive statistical procedures include frequency distributions, percentages, means, standard deviations, minimum values, and maximum values. The analysis distinguishes the demographic composition of the sample from the substantive constructs investigated through the structural model.

The descriptive analysis of the three principal constructs provides an initial representation of teacher digital competence (TDC), adaptive pedagogy (AP), and perceived hybrid learning effectiveness (HLE). Each construct is measured using a five-point Likert scale, with higher scores representing more favorable self-reported competence, instructional adaptability, or perceived effectiveness. The mean values indicate the general tendency of participant responses, while standard deviations describe the dispersion of scores across

respondents. Construct-level statistics should be calculated consistently with the specified measurement model, particularly when interpreting multidimensional constructs. Secondary information concerning institutional digital infrastructure and hybrid learning policies may be incorporated to contextualize the survey findings, provided that its source and observation period are identified. Table 2 establishes the descriptive statistical information required for reporting the three research constructs.

Table 1. Demographic and Professional Profile of Respondents

Variable	Categories	Interpretive focus
Teaching experience	Years of service	Classroom management, assessment
Digital technology exposure	Prior use of digital tools	Confidence in online learning
Educational qualification	Highest degree	Access to professional development
Institutional setting	School type and location	Digital resource availability

The demographic and professional characteristics of respondents provide a basis for understanding the educational environments in which digital competence and adaptive pedagogy are practiced. Teaching experience may influence familiarity with classroom management, instructional design, and learner assessment, whereas previous exposure to digital technologies may shape teachers' confidence in managing online learning activities. Differences in educational qualifications and institutional settings may also correspond with variations in professional development opportunities and digital resource availability. These characteristics should be interpreted as contextual attributes rather than established determinants of hybrid learning effectiveness. The descriptive findings can identify differences in the composition of the participating teacher population, but they cannot establish whether particular demographic characteristics significantly influence the structural relationships without further statistical analysis. The inclusion of these variables therefore strengthens the contextual interpretation of the data and identifies potential considerations for subsequent subgroup or control-variable analyses.

The descriptive distributions of teacher digital competence, adaptive pedagogy, and hybrid learning effectiveness are central to interpreting the practical relevance of the proposed structural model. Teacher digital competence encompasses the ability to select, evaluate, and integrate digital resources into instructional activities. Adaptive pedagogy reflects teachers' reported responsiveness to differences in student readiness, participation, and learning progress, while perceived hybrid learning effectiveness represents teachers' evaluations of instructional quality across face-to-face and online environments. Differences among construct means may indicate variations in participants' self-assessments, but mean differences alone do not establish structural relationships or mediation effects. Such relationships require explicit statistical testing through the PLS-SEM model. The interpretation should also recognize that self-reported competence and effectiveness may be affected by social desirability, response styles, and respondents' differing standards for evaluating their own professional practices.

The measurement model evaluation examines the reliability and validity of the observed indicators representing Teacher Digital Competence, Adaptive Pedagogy, and Perceived Hybrid Learning Effectiveness. Reflective measurement models are assessed through outer loadings, internal consistency reliability, convergent validity, and discriminant validity. Indicator loadings of approximately 0.708 or higher generally support indicator reliability, although decisions about lower-loading items should consider their theoretical relevance and the overall quality of the construct. Cronbach's alpha and composite reliability are examined to assess internal consistency, with coefficients between 0.70 and 0.95 generally regarded as

acceptable for established reflective measures. Average variance extracted (AVE) values of at least 0.50 indicate that a construct explains at least half of the variance in its indicators on average. Table 3 presents the measurement model indicators required to establish the psychometric adequacy of the proposed constructs.

The assessment of discriminant validity determines whether the three constructs represent empirically distinguishable dimensions of teaching and learning. The heterotrait–monotrait ratio of correlations (HTMT) provides a commonly recommended method for examining discriminant validity in reflective measurement models. HTMT values below 0.85 or 0.90, depending on the conceptual similarity among constructs, may support discriminant validity, while bootstrap confidence intervals provide additional evidence. The analysis is particularly relevant because digital competence and adaptive pedagogy may share related indicators involving technology-supported instructional adjustment and individualized learning. Conceptual overlap must therefore be considered when evaluating measurement quality. Strong correlations between constructs should not automatically be interpreted as evidence of inadequate discriminant validity, but excessively high HTMT values would require further examination. The measurement model must demonstrate adequate psychometric properties before the interpretation of structural path coefficients and mediation effects can be considered reliable.

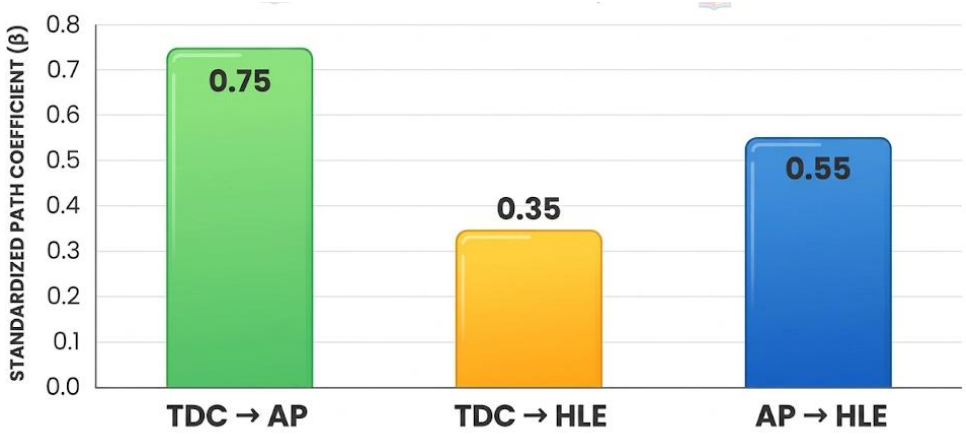


Figure 1. Standardized Path Coefficients for Hybrid Learning Model

The inferential analysis employs Partial Least Squares Structural Equation Modeling to evaluate the hypothesized relationships among teacher digital competence, adaptive pedagogy, and perceived hybrid learning effectiveness. The structural model specifies three direct relationships: TDC → AP, TDC → HLE, and AP → HLE. Standardized path coefficients represent the direction and relative magnitude of these relationships after accounting for other predictors included in the model. Statistical significance is examined using nonparametric bootstrapping with at least 5,000 resamples, enabling the estimation of standard errors and confidence intervals. A path is considered statistically significant at the 5% level when its corresponding confidence interval excludes zero, consistent with the selected hypothesis-testing procedure. Structural collinearity is evaluated using variance inflation factors (VIF), while the explanatory capacity of the model is examined through coefficients of determination (R^2) and effect sizes (f^2). The results must be interpreted in accordance with the cross-sectional, self-reported nature of the data.

The mediation analysis examines whether Adaptive Pedagogy statistically accounts for an indirect association between Teacher Digital Competence and Perceived Hybrid Learning Effectiveness. The specific indirect effect is calculated as the product of the path coefficient linking digital competence to adaptive pedagogy and the coefficient linking adaptive pedagogy to hybrid learning effectiveness. The bootstrapped confidence interval is used to determine whether the estimated indirect association is statistically distinguishable from zero. The pattern

of direct and indirect effects can help characterize the mediation relationship, although a statistically significant indirect effect should not be interpreted as proof of a causal mechanism in a cross-sectional design. The explanatory power of the model is assessed through R^2 values for Adaptive Pedagogy and Perceived Hybrid Learning Effectiveness. Larger R^2 values indicate a greater proportion of explained variance, but their substantive importance depends on the research context, measurement quality, and comparison with relevant theoretical expectations.

The proposed structural model describes Teacher Digital Competence as a potential predictor of both Adaptive Pedagogy and Perceived Hybrid Learning Effectiveness. The relationship between digital competence and pedagogical adaptability reflects the proposition that teachers who possess stronger technological capabilities may also have greater opportunities to modify instructional strategies, provide differentiated learning activities, and respond to student learning needs. Digital resources may facilitate the use of formative assessments, individualized feedback, flexible learning materials, and alternative participation pathways. The relationship should nevertheless be treated as an empirical hypothesis rather than an established outcome. Teachers may possess substantial technological knowledge without consistently applying adaptive instructional strategies. The statistical evaluation of this relationship therefore provides an opportunity to distinguish professional digital capabilities from their reported application in pedagogical decision-making.

The relationship between Adaptive Pedagogy and Perceived Hybrid Learning Effectiveness represents the second substantive component of the structural framework. Adaptive teaching may contribute to effective hybrid instruction by allowing teachers to adjust learning activities, instructional pacing, feedback procedures, and learning support according to student needs. The proposed mediation pathway suggests that digital competence may be more closely associated with perceived instructional effectiveness when teachers also demonstrate pedagogical adaptability. The interpretation of this relationship requires attention to both direct and indirect coefficients, the measurement model, and the explanatory contribution of each construct. Table 5 presents the structural evaluation indicators required to examine the relationships among the research variables. Statistical associations should be interpreted in terms of explanatory relevance rather than definitive causal influence.



Figure 2. Hybrid Learning Scenario

The contextual application of the structural model can be examined through an illustrative hybrid learning scenario involving teachers who integrate classroom instruction with digital educational activities. A teacher may employ a learning management system to distribute instructional materials, monitor participation, provide formative feedback, and organize learning activities according to student readiness. The digital competence component is represented by the teacher's ability to operate, evaluate, and pedagogically select these technologies. Adaptive pedagogy is reflected in the modification of instructional activities

based on assessment information, student engagement, and differences in learning progress. Perceived hybrid learning effectiveness concerns the teacher's evaluation of how successfully these combined practices support instructional objectives. This scenario illustrates the theoretical relationships in the model and should not be presented as an observed case study unless actual classroom observation or institutional case data are collected.

The illustrative scenario also demonstrates why digital competence and adaptive pedagogy should be evaluated as distinct constructs. A teacher may demonstrate advanced skills in managing digital platforms while employing uniform instructional strategies that offer limited adaptation to individual learning needs. Another teacher may demonstrate moderate technological competence but organize differentiated instructional activities effectively through accessible digital tools and responsive classroom practices. These contrasting instructional possibilities highlight the importance of examining whether digital competence is associated with pedagogical responsiveness rather than assuming that technological proficiency automatically produces effective teaching. The proposed SEM analysis can evaluate associations among teachers' reported competencies and instructional perceptions across the surveyed sample. Actual behavioral differences between instructional settings would require supplementary observations, learning artifacts, or other independent measures.

The contextual explanation of the proposed structural relationships emphasizes the role of pedagogical decision-making in connecting technological capabilities with instructional practices. Digital technologies provide resources for communication, assessment, collaboration, and learning organization, but their educational contribution depends on how teachers select and employ them. Adaptive pedagogy introduces an instructional dimension through which teachers interpret learner information and adjust teaching activities to support differentiated participation and progress. The proposed mediation model therefore provides a plausible account of how digital competence may be associated with perceived hybrid learning effectiveness through pedagogical responsiveness. The empirical strength of this explanation depends on whether the estimated direct and indirect relationships are statistically supported and whether the measurement instruments adequately distinguish technological capability, adaptive teaching, and effectiveness perceptions.

The interpretation of hybrid learning effectiveness must also account for contextual factors beyond teacher digital competence and adaptive pedagogy. Institutional technology infrastructure, professional development opportunities, school leadership, student digital access, subject characteristics, and teachers' instructional workloads may influence hybrid learning experiences. Omitting these factors from the structural model may leave important variation unexplained and create alternative explanations for observed associations. The proposed model should therefore be viewed as a theoretically focused representation of selected teacher-related factors rather than a comprehensive explanation of hybrid learning performance. Future extensions may incorporate institutional support, digital self-efficacy, and learning environment characteristics as additional predictors or moderators. The validity of such extensions would depend on theoretical justification, appropriate measurement, and sufficient statistical power.

The proposed analytical framework identifies Teacher Digital Competence, Adaptive Pedagogy, and Perceived Hybrid Learning Effectiveness as interconnected constructs relevant to understanding post-pandemic hybrid education. The primary interpretive contribution lies in distinguishing teachers' ability to use digital technologies from their capacity to adapt instruction to diverse learning needs. The mediation model provides a structured approach for evaluating whether adaptive pedagogical practices help explain the relationship between digital competence and perceived instructional effectiveness. A statistically supported indirect relationship would provide evidence consistent with the theoretical proposition that technological capabilities are associated with hybrid learning effectiveness partly through instructional adaptability. A nonsignificant relationship would instead require reconsideration

of the proposed mechanism, construct measurement, or contextual conditions. Either result could contribute to a more precise understanding of technology-supported teaching.

The implications of the structural model concern the development of professional learning strategies that address digital and pedagogical competencies together. Evidence demonstrating meaningful relationships among these constructs could support the design of teacher development programs integrating technology use, differentiated instruction, formative assessment, and instructional flexibility. The value of such recommendations would depend on the direction, magnitude, precision, and substantive relevance of the estimated associations. The present reporting structure does not establish which hypotheses are supported because verified survey results have not been supplied. The final Results section should therefore present actual descriptive statistics, measurement validity outcomes, path coefficients, mediation estimates, and explanatory power before drawing substantive empirical conclusions. The distinction between hypothesized relationships and verified findings is essential for maintaining the transparency and credibility expected of an international academic publication.

The proposed structural model identifies teacher digital competence, adaptive pedagogy, and perceived hybrid learning effectiveness as three interconnected dimensions of instructional quality in post-pandemic educational environments. The central analytical proposition suggests that digital competence may contribute to effective hybrid instruction through both direct and indirect relationships involving teachers' pedagogical adaptability. Digital competence encompasses the ability to select, manage, and integrate educational technologies, while adaptive pedagogy reflects the capacity to modify instructional strategies according to students' diverse learning needs. The hypothesized relationships indicate that technological proficiency and pedagogical responsiveness should be examined as complementary professional capabilities rather than interchangeable dimensions of teacher effectiveness. The study's principal contribution lies in specifying a structural framework that can distinguish technological competence from the instructional processes through which digital resources are applied. Empirical confirmation of these relationships requires validated measurement instruments, statistically supported structural coefficients, and reliable estimates of direct and indirect effects.

The relationship between teacher digital competence and perceived hybrid learning effectiveness represents the first major component of the proposed model. Teachers possessing stronger digital competencies may be better equipped to organize online instructional resources, facilitate technology-supported classroom activities, conduct digital assessments, and maintain communication across physical and virtual learning environments. These capabilities provide potential opportunities to improve instructional organization, learner accessibility, and educational engagement. The relationship is nevertheless conditional because effective learning depends on how technological resources are selected and integrated into teaching practices. Digital competence should therefore be interpreted as an enabling professional capability rather than a sufficient condition for successful hybrid instruction. A statistically significant positive relationship would support the proposition that higher digital competence is associated with more favorable perceptions of hybrid learning effectiveness. The magnitude and practical importance of this association would need to be evaluated through standardized path coefficients, confidence intervals, and effect-size estimates.

The proposed relationship between teacher digital competence and adaptive pedagogy provides a second dimension for understanding technology-supported teaching practices. Teachers with stronger digital competencies may possess greater opportunities to diversify instructional materials, monitor student progress, provide individualized feedback, and adjust learning activities according to varying levels of student readiness. Adaptive pedagogy introduces a pedagogical dimension that extends beyond the operational use of technology by emphasizing instructional flexibility, learner-centered decision-making, and responsiveness to educational differences. The structural relationship between these constructs is particularly

relevant to post-pandemic hybrid learning, where teachers must coordinate classroom-based instruction with digitally mediated educational activities. The model therefore examines whether technological capability is positively associated with pedagogical adaptability. Evidence supporting this relationship would suggest that teacher digital competence should be assessed partly in relation to its pedagogical application rather than exclusively through the frequency or sophistication of technology use.

The mediating role of adaptive pedagogy constitutes the central analytical proposition of the investigation. The proposed model suggests that digital competence may be associated with perceived hybrid learning effectiveness partly through teachers' capacity to adapt instructional strategies to learners' changing needs. This indirect relationship provides a more detailed explanatory structure than a model considering technological competence and learning effectiveness independently. A statistically significant indirect effect would indicate that adaptive pedagogy accounts for part of the observed association, although cross-sectional mediation cannot independently demonstrate a causal process. The interpretation would also depend on whether the direct relationship between digital competence and hybrid learning effectiveness remains statistically distinguishable from zero after accounting for adaptive pedagogy. The model consequently offers a framework for examining the relative contributions of technological capability and pedagogical responsiveness to hybrid teaching, while recognizing that the actual pattern of relationships must be established through empirical analysis.

The conceptual relationship between teacher digital competence and instructional effectiveness is consistent with the European Framework for the Digital Competence of Educators developed by Redecker (2017). DigCompEdu conceptualizes educator digital competence across six areas, including professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence. This multidimensional framework emphasizes that effective technology integration involves pedagogical judgment rather than merely the ability to operate digital applications. The proposed research model extends this perspective by examining whether digital competence is associated with adaptive pedagogical practices and perceived hybrid learning effectiveness. The distinction is significant because competency frameworks identify relevant professional capabilities but do not automatically establish the structural relationships among competence, instructional adaptability, and educational outcomes. The present study therefore uses DigCompEdu as a conceptual foundation while proposing an empirically testable relationship between technological and pedagogical dimensions of professional teaching.

The importance of differentiating technological proficiency from pedagogical competence is reinforced by Claro et al. (2024), who conducted a systematic review of quantitative studies examining in-service teachers' digital competencies. Their findings identified considerable variation in how digital competence was conceptualized and measured, with greater emphasis on technological applications for teaching preparation and instructional delivery than on teachers' abilities to develop student-centered activities and competencies. This observation is particularly relevant to the proposed model because adaptive pedagogy emphasizes the modification of instructional practices according to student needs. The present investigation seeks to address this conceptual distinction by treating teacher digital competence and adaptive pedagogy as separate but related constructs. The relationship between them provides an opportunity to examine whether teachers' technological capabilities correspond with flexible instructional practices. The proposed contribution lies in testing this relationship within post-pandemic hybrid learning environments rather than assuming that digital competence and adaptive teaching are equivalent educational attributes.

The proposed mediating role of adaptive pedagogy has a particularly close relationship with the research conducted by Liu and Aziku (2025), who investigated adaptive instructional pedagogy, STEM digital pedagogical practices, and instructional integration using PLS-SEM

and data from 15,983 teachers participating in PISA 2022. Their research reported significant associations between digital pedagogical practices, adaptive instructional pedagogy, and digital instructional integration. This study provides an important empirical foundation for considering adaptive pedagogy within structural models of technology-supported teaching. The present investigation must therefore avoid claiming that the integration of digital practices and adaptive pedagogy represents an entirely unexplored research area. Its more defensible contribution concerns the distinct conceptualization of teacher digital competence, the assessment of perceived hybrid learning effectiveness, and the specific post-pandemic instructional context. Demonstrating added explanatory value over existing models would strengthen the claim of originality.

The methodological orientation of the proposed research is consistent with recommendations concerning the application of PLS-SEM in educational studies. Hair and Alamer (2022) explained the relevance of PLS-SEM for research involving latent constructs, complex structural relationships, and predictive analytical objectives. Their methodological discussion emphasizes the importance of selecting a structural modeling approach according to the characteristics of the research problem rather than applying it solely because of its popularity. The present study adopts PLS-SEM to assess the measurement properties of teacher digital competence, adaptive pedagogy, and perceived hybrid learning effectiveness while estimating direct and indirect structural relationships. Its methodological contribution is not the introduction of a new statistical technique but the use of an integrated model to examine the potential explanatory role of adaptive pedagogy. The quality of this contribution depends on construct validity, appropriate model specification, transparent reporting, and theoretically justified interpretations of the estimated relationships.

The proposed relationships signify a broader transformation in the professional competencies required of teachers operating within post-pandemic hybrid educational environments. Educational technology has increasingly become embedded within instructional planning, communication, assessment, and classroom management, creating expectations that teachers can coordinate digital and conventional learning experiences. The central concern is no longer limited to whether teachers possess technological skills but extends to how these skills are translated into effective instructional decisions. Digital competence should consequently be understood as a professional capability that acquires educational significance through its relationship with teaching practices. Adaptive pedagogy provides a potentially important perspective for interpreting this relationship because it emphasizes instructional responsiveness and the capacity to address learner diversity. The proposed framework therefore reflects a movement from technology-centered professional development toward a more integrated understanding of digital and pedagogical competence.

The conceptual role of adaptive pedagogy signifies the importance of teacher agency in technology-supported learning environments. Teachers are not merely users of educational technologies but professionals who interpret classroom conditions, evaluate student learning evidence, and determine how instructional resources should be employed. Technological systems may provide access to learning materials, assessment information, and communication tools, yet teachers remain responsible for making contextually appropriate instructional decisions. Adaptive pedagogy draws attention to these professional judgments by emphasizing the modification of teaching strategies according to educational needs. The proposed model suggests that the effectiveness of digital competence may depend partly on teachers' capacity to make pedagogically meaningful adjustments. This interpretation is consistent with the broader emphasis on professional agency and judgment in evolving digital competence frameworks, including the European Commission's ongoing update of DigCompEdu.

The emphasis on perceived hybrid learning effectiveness signifies a methodological distinction between educational performance and participants' evaluations of their own teaching practices. Teachers may report high levels of digital competence and pedagogical

adaptability while students experience different levels of engagement, accessibility, or academic achievement. Self-reported measures provide valuable information about professional perceptions and instructional experiences, but they do not independently establish objective educational effectiveness. The proposed structural model should therefore be interpreted within the boundaries of its measurement approach. Significant relationships among self-reported constructs would indicate statistical associations between teachers' perceptions rather than direct evidence of improved student learning outcomes. This distinction is particularly important when interpreting the practical significance of structural coefficients. The framework consequently highlights the need to incorporate additional performance-based indicators and independent educational outcome measures in future investigations.

The proposed mediation framework also signifies the importance of distinguishing educational mechanisms from statistical associations. A statistically significant indirect effect may be consistent with the proposition that digital competence operates through adaptive pedagogy, but alternative explanations remain possible. Teachers with stronger pedagogical expertise may be more motivated to develop digital capabilities, institutional support may influence both competencies, or favorable perceptions of instructional effectiveness may shape teachers' self-evaluations. The cross-sectional nature of the proposed research limits the ability to establish temporal ordering among the constructs. The theoretical model provides a structured explanation of their possible relationships, but causal interpretation requires stronger research designs and additional evidence. The significance of the study therefore lies in its capacity to identify and evaluate theoretically meaningful associations while providing a foundation for future investigations of their underlying processes.

The theoretical implication of the proposed model concerns the integration of teacher digital competence and adaptive pedagogy within a coherent explanation of hybrid learning effectiveness. Digital competence frameworks identify the technological and pedagogical capabilities required of contemporary educators, while adaptive teaching perspectives emphasize instructional responsiveness to student differences. The proposed structural model connects these domains by examining whether adaptive pedagogy contributes to explaining the association between technological capability and perceived instructional effectiveness. This integration provides a basis for evaluating whether digital competence and pedagogical adaptability represent empirically distinct dimensions with complementary explanatory roles. Evidence supporting the proposed mediation relationship would strengthen the argument that technology-related teacher competencies should be interpreted within broader pedagogical processes. Theoretical development would nevertheless require examination of competing explanations, additional contextual variables, and the extent to which the model remains consistent across different educational settings.

The pedagogical implication concerns the design of professional development programs that integrate technological proficiency with adaptive instructional capabilities. Teacher training frequently includes instruction on digital applications, learning management systems, multimedia resources, and online assessment tools. Such activities may improve operational familiarity without necessarily ensuring that technologies are employed to address differences in student readiness and learning progress. The proposed framework suggests that professional development could become more educationally relevant when digital skills training is connected with differentiated instruction, formative assessment, flexible learning design, and personalized feedback. Teachers should have opportunities to practice adapting instructional materials and evaluating the consequences of their pedagogical decisions in realistic hybrid learning scenarios. These recommendations remain provisional until empirical findings identify which competencies are most strongly associated with perceived or independently measured instructional effectiveness.

The institutional implication relates to the importance of creating organizational conditions that support sustained digital and pedagogical development. Educational institutions

influence hybrid learning through technology infrastructure, professional learning opportunities, instructional policies, administrative support, and the availability of appropriate digital resources. Teachers may possess substantial technological competence while experiencing limitations in implementing adaptive instruction because of restricted access to devices, large class sizes, limited preparation time, or inadequate institutional support. The proposed model focuses on teacher-related competencies, but its interpretation must recognize that these competencies operate within organizational environments. Institutional strategies should therefore avoid treating individual teacher capability as the sole determinant of hybrid learning effectiveness. A comprehensive approach would combine professional development with accessible technologies, supportive instructional policies, adequate preparation time, and opportunities for collaborative pedagogical reflection.

The educational policy implication involves the potential refinement of teacher competency standards and professional evaluation frameworks. Digital competence is often assessed through technological knowledge, frequency of application use, and familiarity with educational platforms. The proposed integration of adaptive pedagogy suggests that evaluation frameworks may also need to consider how teachers modify instructional activities, use assessment information, and respond to different learning needs. Competency-based professional development could consequently emphasize the relationship between technological capabilities and pedagogical decision-making. Policymakers and educational administrators would benefit from distinguishing self-reported competence from demonstrated instructional performance when designing evaluation systems. The model provides a basis for considering these distinctions, although policy recommendations should ultimately depend on verified empirical evidence and the practical feasibility of implementation across educational institutions.

The potential relationship between teacher digital competence and perceived hybrid learning effectiveness can be explained through the instructional opportunities created by technological proficiency. Teachers who possess stronger digital competencies may be better equipped to organize educational materials, maintain online communication, integrate interactive resources, and monitor student participation across different learning environments. These capabilities can reduce certain operational barriers associated with coordinating face-to-face and digitally mediated instruction. Effective management of educational technologies may also support timely feedback and more flexible access to learning resources. The educational benefits of these capabilities, however, depend on their alignment with instructional objectives and learner characteristics. Technological proficiency may improve the efficiency of instructional delivery without necessarily improving the quality of learning activities. The proposed positive association therefore reflects an enabling relationship rather than an assumption that digital competence automatically produces educational effectiveness.

The relationship between digital competence and adaptive pedagogy can be explained through the capacity of digital tools to provide additional instructional options and information about student learning. Digital assessment systems can facilitate the collection of formative evidence, while learning management platforms can support the distribution of differentiated materials and alternative learning activities. Teachers who understand how to employ these resources may have greater flexibility in responding to differences in learning readiness, participation, and progress. Adaptive pedagogy requires more than access to such information because teachers must interpret evidence and select appropriate instructional responses. The proposed relationship consequently depends on the interaction between technological knowledge and pedagogical judgment. Digital competence may expand instructional possibilities, while adaptive pedagogy determines how those possibilities are translated into learner-responsive practices.

The potential association between adaptive pedagogy and hybrid learning effectiveness can be explained through the diversity of educational experiences encountered within hybrid

instructional environments. Students may differ in digital access, independent learning skills, academic readiness, prior knowledge, and preferred forms of educational support. Uniform instructional strategies may not adequately address these differences, particularly when learning activities occur across physical and virtual settings. Adaptive pedagogy offers a mechanism for adjusting instructional content, learning activities, assessment procedures, and feedback according to emerging student needs. Such adjustments may strengthen participation and support perceptions of instructional effectiveness when they are appropriately designed and implemented. Adaptive teaching also introduces challenges involving teacher workload, instructional consistency, and resource availability. The relationship between adaptation and effectiveness should therefore be examined empirically rather than assumed to be universally positive.

The proposed mediating role of adaptive pedagogy can be understood through the distinction between professional capabilities and their practical application. Digital competence represents teachers' capacity to employ educational technologies, whereas adaptive pedagogy represents the instructional decisions through which those capabilities may become relevant to diverse learners. A teacher may possess extensive knowledge of digital tools but use them primarily for distributing standardized content. Another teacher may apply similar technological capabilities to differentiated assessment, individualized feedback, and flexible learning activities. These differences illustrate why adaptive pedagogy may help explain variation in perceived hybrid learning effectiveness among teachers with comparable levels of digital competence. The proposed mechanism remains theoretical until the indirect relationship is evaluated statistically and supported by appropriate evidence. Cross-sectional SEM can assess the consistency of the observed associations with this explanation, but it cannot independently determine the causal direction of the relationships.

The immediate research priority is to evaluate the proposed structural model using a sufficiently powered and appropriately sampled dataset of teachers with direct experience implementing post-pandemic hybrid learning. The measurement instruments should demonstrate content validity, internal consistency, convergent validity, and discriminant validity before structural relationships are interpreted. Particular attention should be given to distinguishing teacher digital competence from adaptive pedagogy because some dimensions of established digital competence frameworks already incorporate pedagogical responsiveness and learner empowerment. Excessive conceptual overlap could produce misleading structural relationships or compromise the interpretation of mediation. The final analysis should report standardized path coefficients, confidence intervals, indirect effects, explanatory power, effect sizes, and relevant predictive assessments. Transparent reporting would enable researchers to determine whether the proposed mediation model provides meaningful explanatory value beyond simpler alternative models.

The second priority involves strengthening the measurement of hybrid learning effectiveness through multiple sources of evidence. Teacher self-reports provide information about perceived instructional quality but may not accurately represent student learning outcomes or actual classroom practices. Future research should incorporate student assessments, engagement records, instructional observations, and independently evaluated teaching artifacts where feasible. The integration of multiple data sources would reduce reliance on a single response method and provide a stronger basis for evaluating the educational relevance of digital competence and adaptive pedagogy. Longitudinal measurement could further establish whether changes in teacher competencies precede changes in instructional practices and learning outcomes. Such an approach would support a more rigorous examination of the proposed explanatory mechanism and help distinguish short-term perceptions from sustained educational development.

The third priority concerns examining contextual differences in the relationships among digital competence, adaptive pedagogy, and hybrid learning effectiveness. Educational level,

institutional resources, teaching experience, subject specialization, student characteristics, and digital infrastructure may influence how teachers apply technological and pedagogical competencies. Multigroup analysis could investigate whether structural relationships differ across appropriately defined teacher categories, provided that measurement invariance and adequate group-specific sample sizes are established. Additional models could incorporate institutional support, professional development participation, digital self-efficacy, and instructional workload as theoretically justified explanatory variables. Comparative investigations across educational institutions and geographical settings would strengthen understanding of the conditions under which the proposed relationships are most relevant. These extensions should prioritize theoretical coherence and measurement quality rather than increasing model complexity without sufficient justification.

The long-term direction for research and educational practice is to develop and evaluate integrated professional development interventions that combine digital competence with adaptive instructional strategies. Intervention programs could include digital assessment training, differentiated learning design, reflective teaching activities, and practical exercises involving hybrid instructional scenarios (Boeru, 2026). Quasi-experimental or randomized designs, where feasible, would provide stronger evidence regarding whether these interventions improve instructional adaptability and educational outcomes. Repeated assessments could determine whether professional development produces sustained changes in teaching practices rather than temporary improvements in confidence or self-reported competence. The proposed structural model provides a foundation for identifying relevant competencies and potential pathways for intervention, but its practical significance ultimately depends on empirical validation. Future scholarship should therefore move beyond identifying statistical associations toward evaluating the instructional processes through which digital and pedagogical capabilities contribute to meaningful learning experiences.

CONCLUSION

The study highlights the interconnected roles of teacher digital competence and adaptive pedagogy in explaining perceived hybrid learning effectiveness within post-pandemic educational environments. The central insight of the proposed structural model is that technological proficiency and pedagogical adaptability represent distinct yet complementary dimensions of effective instructional practice. Teacher digital competence provides the technological capabilities necessary to manage digital resources, facilitate online interactions, and conduct technology-supported assessments, while adaptive pedagogy emphasizes instructional flexibility, differentiated learning strategies, and responsiveness to students' diverse learning needs. The most distinctive proposition concerns the mediating role of adaptive pedagogy, suggesting that digital competence may be associated with hybrid learning effectiveness both directly and indirectly through adaptive instructional practices. This relationship offers a more comprehensive perspective on technology-supported teaching by emphasizing the pedagogical application of digital capabilities rather than technological proficiency alone. Empirical confirmation of these relationships, including their direction, magnitude, and statistical significance, remains dependent on verified Structural Equation Modeling results.

The primary contribution of this research is the development of an integrated conceptual and analytical framework connecting teacher digital competence, adaptive pedagogy, and perceived hybrid learning effectiveness within a unified structural model. Conceptually, the study extends existing discussions of digital competence by positioning adaptive pedagogy as a potential explanatory mechanism through which technological capabilities are associated with instructional effectiveness. Methodologically, the application of Partial Least Squares Structural Equation Modeling (PLS-SEM) provides a systematic approach for evaluating

construct reliability, convergent and discriminant validity, direct structural relationships, and indirect mediation effects. The proposed framework distinguishes teachers' capacity to use digital technologies from their ability to translate those capabilities into flexible and learner-responsive instructional practices. This distinction contributes to the refinement of teacher competency evaluation and offers a theoretical foundation for designing professional development programs that integrate digital literacy, differentiated instruction, and adaptive assessment. The study's added value lies in specifying and evaluating these relationships within post-pandemic hybrid learning contexts rather than introducing a new statistical technique.

The study is constrained by its proposed cross-sectional quantitative design, reliance on teachers' self-reported perceptions, and potential limitations in sampling representativeness, which restrict causal interpretation and generalizability across educational contexts. The absence of verified empirical estimates in the present manuscript further prevents definitive conclusions regarding the explanatory power of the structural model and the statistical significance of the hypothesized mediation effect. Self-reported digital competence and perceived instructional effectiveness may also be influenced by common method bias, social desirability, and differences in respondents' interpretations of questionnaire items. Future research should employ longitudinal, mixed-methods, and experimental or quasi-experimental designs to investigate the temporal relationships among digital competence, adaptive pedagogy, and hybrid learning outcomes. Additional investigations should incorporate classroom observations, student achievement data, learning analytics, and independently assessed instructional performance to strengthen measurement validity. Comparative studies across educational levels, institutional types, and geographical settings are also recommended to evaluate the stability of the proposed relationships. Future model development should examine institutional support, digital self-efficacy, teaching experience, and technological infrastructure as potential moderating or explanatory variables, thereby providing stronger empirical foundations for evidence-based teacher professional development and sustainable hybrid learning practices.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used Grammarly to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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