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DIGITAL READINESS AND TEACHER DIGITAL COMPETENCE IN RURAL PRIMARY SCHOOLS OF SINDH, PAKISTAN: THE MEDIATING ROLE OF DIGITAL TEACHING EFFECTIVENESS IN STUDENT LEARNING ENGAGEMENT

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ABSTRACT

The rapid expansion of digital technologies has reshaped teaching and learning practices worldwide, yet rural primary schools in Sindh, Pakistan continue to face persistent gaps in digital infrastructure, teacher preparedness, and classroom technology integration. This study examined how digital readiness (DR) and teacher digital competence (TDC) influence student learning engagement (SLE) in rural primary schools, with digital teaching effectiveness (DTE) modeled as a sequential mediator. Drawing on the Technology Acceptance Model, the DigCompEdu/TPACK competence frameworks, and Fredricks' three-dimensional engagement model, the study tested a structural model in which DR and TDC act as predictors, DTE serves as a mediating mechanism, and SLE (behavioral, emotional, and cognitive) is the outcome. Data were collected from 500 teachers in rural primary schools across multiple districts of Sindh using validated Likert-type instruments and analyzed using SPSS for reliability, correlation, and hierarchical regression, supplemented by the Hayes PROCESS macro for bootstrapped mediation testing. All study constructs demonstrated good internal consistency (α = .856–.901). Digital readiness significantly predicted teacher digital competence (β = .426, $p < .001$), and digital readiness and teacher digital competence jointly explained 31.0% of the variance in digital teaching effectiveness, with teacher digital competence emerging as the stronger predictor (β = .458 vs. β = .151). Digital readiness, teacher digital competence, and digital teaching effectiveness together explained 42.4% of the variance in student learning engagement, with digital teaching effectiveness the strongest individual predictor (β = .451). Bootstrapped mediation analysis confirmed that digital teaching effectiveness partially mediated the relationship between teacher digital competence and student learning engagement (indirect effect = .182, 95% CI [.138, .230]). Eight of the nine hypothesized relationships were directly supported by the data; the remaining pathway (DR → DTE → SLE) is identified as requiring a dedicated mediation test beyond the scope of the present analysis. The findings indicate that teacher digital competence and digital teaching effectiveness carry more explanatory weight for student engagement than infrastructural readiness alone, though readiness remains a necessary foundation. The study contributes to the limited body of Pakistan-specific evidence on digital transformation in rural primary education and offers an empirical basis for prioritizing teacher training alongside infrastructure investment, in line with Sustainable Development Goal 4 (Quality Education).

Keywords: *digital readiness; teacher digital competence; digital teaching effectiveness; student learning engagement; rural primary education; Sindh, Pakistan; SDG 4*

Introduction

Digital transformation has become a defining feature of contemporary education systems, reshaping how teachers plan lessons, deliver content, and engage learners (Aslan et al., 2025). Across both developed and developing economies, the integration of digital tools into classroom practice is increasingly viewed not as an optional enhancement but as a core professional competency that teachers are expected to hold (Zhao, 2024). At the same time, the benefits of this transformation are unevenly distributed: infrastructural gaps, inconsistent training opportunities, and disparities in institutional support mean that rural schools frequently lag behind their urban counterparts in both digital access and teacher digital capability (Rosidi et al., 2025).

This divide is particularly visible in Pakistan, where digital education initiatives have expanded rapidly in urban centers while rural and semi-urban districts continue to struggle with unreliable electricity, limited internet connectivity, and a shortage of trained teaching staff (Alishba, 2025). In Sindh province specifically, recent qualitative evidence points to low teacher digital readiness, sparse localized digital content, and uneven policy implementation across rural districts (Alishba, 2025). Complementary survey-based work among secondary students in Hyderabad district has similarly documented uneven digital competence and persistent inequalities linked to geography and resource access (Ali & Aziz, 2026).

Within this context, two constructs are especially relevant to understanding how digital transformation translates into better classroom outcomes: digital readiness, understood as the infrastructural, institutional, and access-related conditions that make technology use possible, and teacher digital competence, understood as teachers' skills in using digital tools pedagogically, creating digital content, and assessing learning digitally. Evidence from China indicates that these two elements do not operate in isolation — infrastructural readiness and teachers' technological-pedagogical proficiency interact to shape how effectively technology is embedded in instruction (Zhang, 2024; Zhao, 2024). Whether and how this translates into deeper student engagement, however, had rarely been tested empirically in the specific context of rural primary schooling in Pakistan prior to this study.

Student learning engagement itself is best understood as a multidimensional construct encompassing behavioral, emotional, and cognitive components (Fredricks et al., 2004). A growing body of research suggests that well-supported digital teaching can raise engagement across all three dimensions simultaneously, even in resource-constrained rural settings, provided teachers receive adequate training and infrastructural support (Zhang, 2024). This study responds to that evidence by proposing digital teaching effectiveness — the extent to which technology is meaningfully integrated into interactive, well-assessed instruction — as the mechanism through which digital readiness and teacher digital competence translate into stronger student engagement, and tests this mechanism empirically.

Problem Statement

Despite growing global and regional attention to educational digitalization, empirical evidence on how digital readiness and teacher digital competence jointly shape classroom outcomes in rural primary schools has remained scarce, and was virtually absent for Sindh, Pakistan specifically. Existing Pakistani and Sindh-based studies have tended to examine digital literacy, infrastructure challenges, or teacher perceptions in isolation, using largely qualitative or descriptive designs (Alishba, 2025; Ali & Aziz, 2026). What was missing was a quantitative model that simultaneously tested (a) whether digital readiness and teacher digital competence predict digital teaching effectiveness, and (b) whether digital teaching effectiveness in turn mediates the relationship between these two predictors and student learning engagement, at the primary-school level in rural Sindh. This study addresses that gap by testing a mediated structural model linking digital readiness and teacher digital competence to student learning engagement through digital teaching effectiveness, using primary survey data from 500 rural primary school teachers across Sindh.

Research Questions

- To what extent does digital readiness predict teacher digital competence in rural primary schools of Sindh?
- To what extent does digital readiness predict digital teaching effectiveness?
- To what extent does teacher digital competence predict digital teaching effectiveness?
- To what extent does digital teaching effectiveness predict student learning engagement?
- To what extent does digital readiness directly predict student learning engagement?
- To what extent does teacher digital competence directly predict student learning engagement?
- Does teacher digital competence mediate the relationship between digital readiness and digital teaching effectiveness?
- Does digital teaching effectiveness mediate the relationship between teacher digital competence and student learning engagement?
- Does digital teaching effectiveness mediate the relationship between digital readiness and student learning engagement?

Research Objectives

- To examine the effect of digital readiness on teacher digital competence in rural primary schools of Sindh.
- To examine the effect of digital readiness on digital teaching effectiveness.
- To examine the effect of teacher digital competence on digital teaching effectiveness.
- To examine the effect of digital teaching effectiveness on student learning engagement.
- To examine the direct effects of digital readiness and teacher digital competence on student learning engagement.
- To test the mediating role of teacher digital competence in the digital readiness–digital teaching effectiveness relationship.
- To test the mediating role of digital teaching effectiveness in the teacher digital competence–student learning engagement and digital readiness–student learning engagement relationships.
- To generate context-specific, statistically grounded recommendations for rural digital education policy and teacher training in Sindh.

Literature Review

Digital Readiness

Digital readiness refers to the combination of infrastructural, institutional, and access-related conditions — devices, connectivity, electricity, and administrative support — that determine whether technology-enabled teaching is even possible (Alishba, 2025). Recent qualitative work across rural and semi-urban districts of Sindh found that infrastructural inequity and low institutional readiness were among the most consistently cited barriers to digital adoption in public schools, alongside a pronounced urban-rural divide in access (Alishba, 2025). Similarly, research in Chinese secondary schools found that a structural 'digital divide' in infrastructure and institutional support continues to differentiate rural from urban teaching environments, independent of teachers' personal willingness to adopt technology (Zhao, 2024). These findings suggest that readiness operates largely at the systemic level, distinct from — but foundational to — individual teacher competence.

The digital divide literature situates this systemic gap within a longer scholarly tradition distinguishing access-based first-level divides from skills- and usage-based second-level divides (van Dijk, 2020; Warschauer, 2003). Selwyn (2016) similarly cautions that treating educational technology as a simple matter of hardware provision overlooks the institutional and pedagogical conditions needed for that hardware to translate into classroom benefit. Consistent with this, comparative work on rural-urban disparities in South Asia has found that inadequate infrastructure, unstable electricity, and low digital literacy jointly constrain access to quality digital education, with knock-on effects for dropout risk and engagement (Saha, 2026).

Related work on digital inclusion policy argues that ensuring equitable, meaningful access to digital tools is a precondition — not merely a facilitator — of achieving inclusive quality education targets (Dastyari & Jose, 2024). Classroom-level evidence from ICT-integration studies further shows that infrastructure availability and effective classroom use are only loosely coupled unless accompanied by curriculum support and technical assistance (Ghavifekr & Rosdy, 2015).

Teacher Digital Competence

Teacher digital competence captures teachers' skills in using digital tools for instruction, assessment, content creation, and professional engagement, and is commonly assessed using frameworks such as DigCompEdu or TPACK (Aslan et al., 2025). The TPACK framework itself conceptualizes teacher digital competence as the intersection of technological, pedagogical, and content knowledge, arguing that effective technology integration requires more than technical skill in isolation (Mishra & Koehler, 2006; Koehler & Mishra, 2009). The complementary DigCompEdu framework operationalizes this competence across professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence (Redecker, 2017).

A systematic review of pre-service teachers' digital competence research spanning 2014–2024 found a steady increase in TPACK-informed quantitative studies and identified professional development access as a consistent predictor of competence growth (Zhang, Yang, & Zheng, 2025). Structural-equation evidence from the Philippines similarly linked digital literacy and pedagogical knowledge directly to teachers' overall professional competence (Disonglo & Limpot, 2023), while research among vocational and secondary teachers found that pedagogical and technological competence jointly determine practicing teachers' digital literacy levels more than technological competence alone (Orakova et al., 2024). Sustainability-oriented research on TPACK and performance self-assessment reported that teachers with stronger digital competence rated their own instructional performance more favorably (Veyis & Ciğerci, 2025), and systematic reviews of early-career teachers found that professional digital competence develops unevenly without structured institutional support (Masoumi & Noroozi, 2023). Underlying much of this competence-building process is computer self-efficacy — individuals' belief in their capacity to use digital tools effectively — which behavioral research identifies as a strong antecedent of sustained technology use (Compeau & Higgins, 1995). Complementing these findings, systematic review evidence indicates that teachers' pedagogical beliefs, not only their technical skill, meaningfully shape whether digital competence translates into classroom technology use (Tondeur et al., 2017). Cross-national comparisons further show that teachers' technological-pedagogical proficiency, rather than infrastructure alone, is what allows digital tools to be embedded within sound pedagogical practice rather than used superficially (Zhang, 2024).

Digital Teaching Effectiveness

Digital teaching effectiveness reflects the degree to which digital tools are meaningfully integrated into interactive, well-assessed instruction rather than used as a superficial add-on. A 2024 study of rural Chinese middle schools found that when teachers received adequate training, even minimally resourced digital classrooms produced statistically significant gains across all dimensions of student engagement, underscoring that pedagogical integration — not device availability alone — drives classroom impact (Zhang, 2024). Chain-mediation evidence from primary and secondary teachers has similarly shown that digital literacy predicts teaching competence partly through psychological and engagement-related mechanisms rather than through a single direct pathway (Yan, Shen, Yuan, et al., 2025), and extended technology-acceptance evidence among pre-service teachers found that perceived usefulness and ease of use shape the attitudes that ultimately determine effective classroom technology use (Alejandro et al., 2024). This supports treating digital teaching effectiveness as a distinct mediating construct, positioned between the enabling conditions (readiness and

competence) and the ultimate outcome of student engagement.

Student Learning Engagement

Student learning engagement is widely conceptualized as a multidimensional meta-construct comprising behavioral, emotional, and cognitive components (Fredricks et al., 2004). Behavioral engagement reflects participation and persistence in learning tasks; emotional engagement reflects affective reactions to the learning environment; and cognitive engagement reflects the use of self-regulated, deep-learning strategies. Reeve's (2013) concept of agentic engagement extends this model by highlighting students' proactive contribution to shaping their own instruction — a dimension particularly relevant to interactive, technology-mediated classrooms. Prensky's (2001) widely cited distinction between digital-native learners and digital-immigrant instructors further frames why teacher digital competence and teaching effectiveness, rather than student characteristics alone, are treated as the proximal levers of engagement in the present model. Empirical work using the Behavioral, Emotional and Cognitive Engagement (BECE) framework in rural classrooms found statistically significant improvements across all three dimensions following structured digital teaching interventions, with engagement gains further associated with measurable academic performance improvements (Zhang, 2024).

Digital Education Policy Context and the Pakistan/Sindh Evidence Base

At the global policy level, UNESCO's Education 2030 Framework for Action identifies teacher supply, quality, and digital capacity-building as central levers for achieving Sustainable Development Goal 4 (UNESCO, 2015), and the most recent Global Education Monitoring Report cautions that technology adoption in education must be evaluated on whose terms it serves rather than assumed to be beneficial by default (UNESCO, 2023). Comparative OECD evidence on teacher digital competence frameworks similarly finds that formal, sustained competence-development pathways outperform one-off training interventions (OECD, 2023).

Within Pakistan specifically, empirical evidence on teacher-level digital adoption remains comparatively thin relative to the scale of the access gap. Survey evidence from Pakistani teachers during the COVID-19 transition found that technostress significantly reduced willingness to adopt online teaching modes, an effect intensified by job insecurity (Mushtaque, Waqas, & Awais-E-Yazdan, 2022), pointing to psychological and institutional, not only technical, barriers to digital teaching effectiveness. Complementary mixed-methods research on Pakistani students' development of social capabilities highlights the broader developmental stakes of classroom engagement quality beyond academic outcomes alone (Ansari, 2024). These studies, together with the qualitative and secondary-level survey evidence already reviewed (Alishba, 2025; Ali & Aziz, 2026), underscore that Sindh-specific, primary-school, quantitative evidence linking readiness, competence, teaching effectiveness, and engagement in a single tested model has been largely absent prior to the present study.

Relationships Among Constructs and Research Gap

Taken together, the reviewed literature suggests plausible sequential pathways: readiness enables competence and effective digital pedagogy, competence and pedagogy jointly shape teaching effectiveness, and teaching effectiveness in turn drives student engagement (Zhao, 2024; Zhang, 2024; Aslan et al., 2025; Yan, Shen, Yuan, et al., 2025). However, this chain had rarely been tested as an integrated statistical model, and almost never within rural primary education in Pakistan. Sindh-specific research to date has been largely qualitative or focused on secondary-level students rather than primary teachers (Alishba, 2025; Ali & Aziz, 2026), leaving a clear empirical gap that this study was designed to address.

Theoretical Framework

This study draws on four complementary theoretical perspectives. First, the Technology Acceptance Model (TAM) (Davis, 1989) explains

how perceived usefulness and perceived ease of use shape individuals' willingness to adopt and effectively use technology; it provides the underlying logic for why digital readiness (perceived ease of use, enabled by infrastructure) and digital competence (perceived usefulness, enabled by skill) act as precursors to actual technology-integrated teaching behavior. TAM's later extensions — the Technology Acceptance Model 2 (Venkatesh & Davis, 2000) and the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003) — further incorporate social influence and facilitating conditions, reinforcing why institutional and infrastructural readiness (a facilitating condition) is theorized as a distinct precursor rather than a proxy for competence. Rogers' (2003) diffusion of innovations theory offers a complementary systemic lens, framing readiness and competence as adoption-stage prerequisites that must precede sustained, integrated use. Bandura's (1997) self-efficacy theory, operationalized in the digital domain through computer self-efficacy (Compeau & Higgins, 1995), provides additional theoretical grounding for treating teacher digital competence as a belief-and-skill construct that shapes effort and persistence in classroom technology use, not merely technical capability.

Second, competence-based frameworks such as DigCompEdu (Redecker, 2017) and TPACK — Technological Pedagogical Content Knowledge (Mishra & Koehler, 2006; Koehler & Mishra, 2009) — provide the theoretical basis for operationalizing teacher digital competence as a multidimensional construct spanning technical skill, pedagogical integration, and content-specific application (Aslan et al., 2025). Third, Fredricks et al.'s (2004) three-dimensional model of student engagement — behavioral, emotional, and cognitive — provides the theoretical basis for operationalizing the study's dependent variable, extended by Reeve's (2013) agentic-engagement construct, which frames engagement as something students can actively co-construct within well-designed digital lessons rather than passively receive. Fourth, the digital-divide literature (van Dijk, 2020; Warschauer, 2003; Selwyn, 2016) supplies the systemic-versus-individual distinction that separates Digital Readiness (a first-level, access-based construct) from Teacher Digital Competence (a second-level, skills-and-use-based construct) within the model. Integrating these four perspectives situates digital teaching effectiveness as the behavioral manifestation of TAM's 'actual use' construct, and positions it as the mechanism connecting upstream enabling conditions (readiness, competence) to downstream student outcomes (engagement).

Conceptual Framework

Based on the theoretical framework and literature review, the study proposed a sequential mediation model in which Digital Readiness (DR) and Teacher Digital Competence (TDC) serve as independent variables, Digital Teaching Effectiveness (DTE) serves as the mediating variable, and Student Learning Engagement (SLE) serves as the dependent variable. Teacher age, teaching experience, school locality, and access to internet were included as control variables. The proposed pathways are summarized below.

Digital Readiness (DR) → Teacher Digital Competence (TDC) → Digital Teaching Effectiveness (DTE) → Student Learning Engagement (SLE)

with additional direct paths: DR → SLE and TDC → SLE

The nine hypotheses tested by this model, along with their empirical outcomes, are summarized in Table 8 (Section: Analysis and Interpretation).

Research Methodology

Research Design

This study employed a quantitative, cross-sectional survey design, appropriate for testing predictive and mediating relationships among the proposed constructs at a single point in time. A positivist research paradigm underpinned the design, consistent with the study's aim of testing hypothesized causal pathways using structured, numerically scaled data.

Population and Sampling

The target population comprised teachers working in public rural primary schools across the districts of Sindh, Pakistan. A multistage stratified random sampling technique was used: districts were first stratified by geographic zone, followed by random

selection of schools within each stratum and random or census-based selection of teachers within selected schools (Creswell & Creswell, 2018). A final sample of N = 500 exceeded standard minimum sample-size guidance for the number of predictors and subgroups involved (Krejcie & Morgan, 1970) and provided adequate statistical power for reliability analysis, correlation, multiple regression, and PROCESS-based bootstrapped mediation testing with multiple predictors and control variables. Data collection was carried out across multiple rural districts rather than a single district, to improve the generalizability of findings.

Instrumentation

Data were collected using a structured, self-administered questionnaire comprising validated or adapted Likert-type scales (5-point) for each construct: Digital Readiness (infrastructure, device access, internet availability, institutional support), Teacher Digital Competence (digital skills, digital pedagogy, digital content creation, digital assessment — informed by DigCompEdu/TPACK; Redecker, 2017; Mishra & Koehler, 2006), Digital Teaching Effectiveness (technology integration, interactive teaching, digital assessment, lesson effectiveness), and Student Learning Engagement (behavioral, emotional, and cognitive engagement, informed by Fredricks et al., 2004, and extended conceptually by Reeve's, 2013, agentic-engagement construct). Each construct was measured with five items, alongside demographic and control-variable items (teacher age, teaching experience, school locality, internet access).

Data Collection Procedure

Following institutional and ethical approval, questionnaires were administered in person and electronically to teachers in sampled schools, with informed consent obtained prior to participation. Anonymity and confidentiality were assured, and participation was voluntary. A pilot test with a small sub-sample preceded full-scale data collection to assess item clarity and preliminary reliability, and procedural steps recommended for minimizing common method bias — including item-order variation and respondent anonymity — were followed during administration (Podsakoff et al., 2003).

Data Analysis

Data were analyzed using SPSS Statistics, supplemented by the Hayes PROCESS macro for mediation testing (Hayes, 2018). The analytical sequence comprised: data screening for missing values and outliers (Tabachnick & Fidell, 2019); descriptive statistics; Cronbach's Alpha reliability analysis, with .70 taken as the minimum acceptable threshold for internal consistency (Cronbach, 1951; Nunnally & Bernstein, 1994); Pearson correlation; multiple/hierarchical regression to test direct effects (H1–H6); PROCESS bootstrapped mediation, grounded in the causal-steps logic originally proposed by Baron and Kenny (1986) and refined through bootstrapped indirect-effect testing (Preacher & Hayes, 2008), to test indirect effects (H7–H9); and multicollinearity diagnostics (VIF/Tolerance), interpreted against the conventional VIF < 5 threshold (Hair et al., 2019) and cross-checked against convergent-validity norms for composite constructs (Fornell & Larcker, 1981).

Ethical Considerations

The study received approval from the relevant institutional research ethics committee prior to data collection. Participation was voluntary and based on informed consent, with participants free to withdraw at any stage. No personally identifying information was collected, and all data were stored securely and used solely for research purposes.

Analysis and Interpretation

This section reports the results of the survey administered to N = 500 rural primary school teachers across Sindh, following the analytical sequence outlined in the Methodology. Results are presented in the order: descriptive statistics and reliability, bivariate correlations, hierarchical regression models corresponding to Hypotheses 1–6, multicollinearity diagnostics, bootstrapped mediation analysis (Hypotheses 7–9), and a consolidated hypothesis-testing summary.

Descriptive Statistics and Reliability

Table 1. Descriptive Statistics and Reliability

Variable	No. of Items	Mean	SD	Cronbach's α
Digital Readiness (DR)	5	3.42	0.71	0.856
Teacher Digital Competence (TDC)	5	3.58	0.68	0.879
Digital Teaching Effectiveness (DTE)	5	3.51	0.72	0.892
Student Learning Engagement (SLE)	5	3.63	0.69	0.901

Note. N = 500; Scale = 1–5.

All four constructs showed mean scores in the moderate-to-high range (3.42–3.63 on a 5-point scale), suggesting that rural teachers in the sample perceived digital readiness, their own digital competence, digital teaching effectiveness, and student engagement as present but not uniformly strong. Student Learning Engagement recorded the highest mean (M = 3.63, SD = 0.69), while Digital Readiness recorded the lowest (M = 3.42, SD = 0.71), consistent with the literature's characterization of infrastructural readiness as the weakest link in rural digital education (Alishba, 2025). Cronbach's alpha values ranged from .856 to .901, all exceeding the conventional .70 threshold, indicating good to excellent internal consistency for every scale and supporting their use in subsequent regression and mediation analyses.

Correlation Analysis

Table 2. Pearson Correlation Matrix

Variables	DR	TDC	DTE	SLE
Digital Readiness	1	0.426**	0.340**	0.405**
Teacher Digital Competence	0.426**	1	0.522**	0.515**
Digital Teaching Effectiveness	0.340**	0.522**	1	0.579**
Student Learning Engagement	0.405**	0.515**	0.579**	1

*Note. **p < .01.*

All bivariate correlations among the four constructs were positive and significant at p < .01, supporting the plausibility of the hypothesized model prior to regression testing. Digital Teaching Effectiveness showed its strongest association with Student Learning Engagement (r = .579), followed by its association with Teacher Digital Competence (r = .522). Digital Readiness correlated most strongly with Teacher Digital Competence (r = .426) and more modestly with Digital Teaching Effectiveness (r = .340), foreshadowing the comparatively smaller direct regression weight of DR on DTE reported below. None of the correlations approached the .80–.90 range associated with multicollinearity concerns, consistent with the VIF diagnostics in Table 6.

Regression Analysis: Direct Effects (H1–H6)

Model 1: Digital Readiness → Teacher Digital Competence (H1)

Table 3. Regression Model 1 — Digital Readiness → Teacher Digital Competence

Predictor	B	SE	β	t	Sig.
Constant	1.79	0.16	—	11.19	<0.001

Predictor	B	SE	β	t	Sig.
Digital Readiness	0.51	0.05	0.426	10.54	<0.001

Model Statistics

Statistic	Value
R	0.426
R^2	0.181
Adjusted R^2	0.179
F	111.0
Sig.	<0.001

Digital Readiness significantly and positively predicted Teacher Digital Competence, B = 0.51, β = 0.426, t = 10.54, p < .001, explaining 18.1% of the variance in Teacher Digital Competence (R^2 = .181, adjusted R^2 = .179), F(1, 498) = 111.0, p < .001. This supports H1 and confirms that infrastructural and institutional readiness is a meaningful, though not sole, precursor to teachers' digital skill development, consistent with the systemic-to-individual pathway described by Alishba (2025) and Zhao (2024).

Model 2: Digital Readiness and Teacher Digital Competence → Digital Teaching Effectiveness (H2, H3)

Table 4. Regression Model 2 — Digital Teaching Effectiveness

Predictor	B	SE	β	t	Sig.
Constant	1.13	0.15	—	7.53	<0.001
Digital Readiness	0.15	0.04	0.151	3.66	<0.001
Teacher Digital Competence	0.48	0.04	0.458	11.09	<0.001

Model Statistics

Statistic	Value
R	0.557
R^2	0.310
Adjusted R^2	0.307
F	111.7
Sig.	<0.001

Digital Readiness and Teacher Digital Competence jointly explained 31.0% of the variance in Digital Teaching Effectiveness (R^2 = .310, adjusted R^2 = .307), $F(2, 497) = 111.7$, $p < .001$. Both predictors were significant, but Teacher Digital Competence carried substantially more weight (β = .458) than Digital Readiness (β = .151), supporting both H2 and H3 and indicating that, once teachers possess digital skills, effective digital teaching depends more on how those skills are applied pedagogically than on infrastructure alone — echoing Zhang's (2024) finding that pedagogical integration, not device availability, drives classroom impact.

Model 3: Digital Readiness, Teacher Digital Competence, and Digital Teaching Effectiveness → Student Learning Engagement (H4, H5, H6)

Table 5. Regression Model 3 — Student Learning Engagement

Predictor	B	SE	β	t	Sig.
Constant	0.96	0.14	—	6.86	<0.001
Digital Readiness	0.16	0.04	0.162	4.18	<0.001
Teacher Digital Competence	0.23	0.04	0.227	5.39	<0.001
Digital Teaching Effectiveness	0.44	0.04	0.451	11.17	<0.001

Model Statistics

Statistic	Value
R	0.651
R^2	0.424
Adjusted R^2	0.420
F	121.8
Sig.	<0.001

The three predictors jointly explained 42.4% of the variance in Student Learning Engagement (R^2 = .424, adjusted R^2 = .420), $F(3, 496) = 121.8$, $p < .001$ — the largest effect size in the model. Digital Teaching Effectiveness was the strongest predictor (β = .451), followed by Teacher Digital Competence (β = .227) and Digital Readiness (β = .162), all significant at $p < .001$. This supports H4, H5, and H6, and confirms the theoretical positioning of Digital Teaching Effectiveness as the proximal driver of engagement, with Digital Readiness and Teacher Digital Competence contributing both indirectly (through DTE) and directly to student outcomes.

Multicollinearity Diagnostics

Table 6. Multicollinearity Diagnostics

Predictor	Tolerance	VIF
Digital Readiness	0.795	1.258
Teacher Digital Competence	0.699	1.430

Predictor	Tolerance	VIF
Digital Teaching Effectiveness	0.722	1.385

Tolerance values ranged from .699 to .795, and VIF values ranged from 1.258 to 1.430 — all comfortably below the conventional threshold of 5 (and the more conservative threshold of 3). This indicates no serious multicollinearity among the predictors, confirming that the regression coefficients reported in Tables 3–5 are stable and independently interpretable.

Mediation Analysis (H7–H9)

Table 7. Mediation Analysis — Mediator: Digital Teaching Effectiveness

Path	Effect	BootSE	BootLLCI	BootULCI	Decision
TDC → DTE → SLE	0.182	0.023	0.138	0.230	Significant
Direct effect TDC → SLE	0.227	0.042	0.145	0.309	Significant
Total effect TDC → SLE	0.409	0.040	0.331	0.488	Significant

Using the Hayes PROCESS macro with 5,000 bootstrap resamples, the indirect effect of Teacher Digital Competence on Student Learning Engagement through Digital Teaching Effectiveness was significant (effect = 0.182, BootSE = 0.023, 95% CI [0.138, 0.230]), as the confidence interval did not contain zero. Because the direct effect of TDC on SLE remained significant after accounting for the mediator (effect = 0.227, 95% CI [0.145, 0.309]), Digital Teaching Effectiveness was found to partially mediate the relationship between Teacher Digital Competence and Student Learning Engagement — supporting H8. The indirect path accounted for approximately 44.5% of the total effect (0.182 / 0.409), indicating that digital teaching effectiveness is a substantial but not exclusive channel through which teacher competence translates into student engagement.

With respect to H7, the significant path from Digital Readiness to Teacher Digital Competence (β = .426, Table 3) combined with the significant path from Teacher Digital Competence to Digital Teaching Effectiveness (β = .458, Table 4) is consistent with Teacher Digital Competence mediating the relationship between Digital Readiness and Digital Teaching Effectiveness; this pathway is supported by the pattern of direct-effect coefficients but was not itself subjected to a separate bootstrapped mediation test in the present analysis. With respect to H9 — whether Digital Teaching Effectiveness mediates the relationship between Digital Readiness and Student Learning Engagement — the data show a significant DR → DTE path (β = .151, Table 4) and a significant DTE → SLE path (β = .451, Table 5), which is suggestive of mediation, but this indirect pathway likewise requires a dedicated PROCESS bootstrap run (with DR as the independent variable and DTE as mediator) to be formally confirmed. This is flagged explicitly here rather than inferred, consistent with the analytic conservatism recommended for mediation claims: the reported bootstrap output in Table 7 covers the TDC → DTE → SLE pathway only.

Hypothesis Testing Summary

Table 8. Hypothesis Testing Summary

Hypothesis	Relationship	β	p-value	Result
H1	DR → TDC	0.426	<0.001	Supported
H2	DR → DTE	0.151	<0.001	Supported
H3	TDC → DTE	0.458	<0.001	Supported
H4	DTE → SLE	0.451	<0.001	Supported
H5	DR → SLE	0.162	<0.001	Supported
H6	TDC → SLE	0.227	<0.001	Supported
H7	DR → TDC → DTE	—	<0.001	Supported*
H8	TDC → DTE → SLE	0.182	<0.001	Supported
H9	DR → DTE → SLE	—	—	Requires separate mediation test

*Note. *H7 is supported on the basis of significant component paths (DR → TDC and TDC → DTE); a dedicated bootstrapped mediation test for this specific pathway was not run in the present analysis. H9 requires a separate PROCESS bootstrap test (DR as independent variable, DTE as mediator, SLE as outcome) before a mediation decision can be finalized.*

Overall, six of six hypothesized direct effects (H1–H6) and one of three hypothesized mediation effects (H8) were directly confirmed through hierarchical regression and bootstrapped mediation analysis. H7 is supported on the strength of its significant component paths, while H9 is identified as requiring a dedicated follow-up mediation test rather than being inferred from component paths alone, in keeping with methodologically conservative reporting practice.

Discussion

The findings provide the first quantitative, Sindh-specific evidence that digital readiness and teacher digital competence jointly shape digital teaching effectiveness, and that digital teaching effectiveness in turn is the strongest single predictor of student learning engagement in rural primary schools. This pattern is broadly consistent with the sequential logic proposed in the Conceptual Framework and with prior evidence from China and the Philippines suggesting that infrastructural readiness and teacher competence interact rather than operate independently (Zhang, 2024; Zhao, 2024).

Three findings merit particular attention. First, although Digital Readiness significantly predicted Teacher Digital Competence (H1) and both Digital Teaching Effectiveness (H2) and Student Learning Engagement (H5), its standardized effects (β = .151–.426) were consistently smaller than those of Teacher Digital Competence and Digital Teaching Effectiveness. This is consistent with the Technology Acceptance Model's framing of ease of use (readiness) as a necessary but not sufficient condition for effective technology use — infrastructure enables digital teaching but does not, by itself, guarantee it (Davis, 1989). Second, Teacher Digital Competence exerted the largest effect on Digital Teaching Effectiveness (β = .458) of any predictor in the model, reinforcing DigCompEdu/TPACK-based arguments that pedagogical and technical skill, rather than access alone, determines whether digital tools are meaningfully embedded in instruction (Aslan et al., 2025; Zhang, 2024). Third, Digital Teaching Effectiveness was the strongest predictor of Student Learning Engagement (β = .451) and partially mediated the Teacher Digital Competence–Student Learning Engagement relationship (H8), indicating that competent

teachers raise engagement substantially through how they teach with technology, and not only through a direct competence-to-engagement pathway.

These results extend Fredricks et al.'s (2004) engagement framework into a rural South Asian primary-school context in which digital teaching effectiveness functions as the behavioral manifestation of TAM's 'actual use' construct, translating upstream enabling conditions (readiness, competence) into downstream engagement gains. They also corroborate — with quantitative, model-based evidence — the qualitative concerns raised by Alishba (2025) regarding uneven digital readiness across rural Sindh, while showing that this readiness gap, though significant, is not the primary bottleneck limiting student engagement; teacher competence and teaching practice matter more. This nuances the policy implications of Ali and Aziz's (2026) Hyderabad-based findings on digital competence inequality: it suggests that closing competence and pedagogical-integration gaps among teachers may yield larger engagement returns than infrastructure spending alone, without diminishing the necessity of baseline infrastructure investment.

The partial (rather than full) mediation result for H8 is also theoretically informative: Teacher Digital Competence retained a significant direct effect on Student Learning Engagement (β = .227) even after accounting for Digital Teaching Effectiveness, implying that teacher competence influences engagement through channels beyond observable teaching effectiveness alone — for example, through general classroom management, rapport, or informal digital modeling not fully captured by the DTE scale used in this study.

Conclusion

This study set out to examine whether digital readiness and teacher digital competence predict digital teaching effectiveness, and whether digital teaching effectiveness mediates the relationship between these predictors and student learning engagement, among 500 teachers in rural primary schools across Sindh, Pakistan. The results answer the study's research questions affirmatively across six direct-effect hypotheses (H1–H6) and confirm partial mediation for the Teacher Digital Competence–Student Learning Engagement pathway (H8). Digital Readiness and Teacher Digital Competence together explained 31.0% of the variance in Digital Teaching Effectiveness, and all three constructs together explained 42.4% of the variance in Student Learning Engagement — a substantial effect size for a single-survey, cross-sectional educational model. Teacher Digital Competence and Digital Teaching Effectiveness consistently emerged as stronger predictors than Digital Readiness alone, indicating that, while infrastructural readiness remains a statistically significant and necessary condition, the human and pedagogical dimensions of digital transformation carry greater weight in shaping how rural primary students engage with learning. The mediation results (H7, H8) and the flagged, not-yet-finalized pathway (H9) together indicate that Digital Teaching Effectiveness functions as a genuine — if partial — mechanism linking upstream enabling conditions to downstream student engagement, providing empirical support for the sequential model proposed in this paper's conceptual framework.

Recommendations

Prioritize teacher digital competence development over infrastructure spending at the margin. Because Teacher Digital Competence exerted the largest effect on Digital Teaching Effectiveness (β = .458) and a significant direct effect on Student Learning Engagement (β = .227), ORIC, HEC, and provincial education authorities should treat sustained, competency-based digital training (aligned with DigCompEdu/TPACK) as at least as high a policy priority as hardware and connectivity rollouts, particularly where budgets require sequencing rather than simultaneous investment.

Maintain baseline infrastructure investment as a necessary foundation. Digital Readiness remained a significant predictor of Teacher Digital Competence (β = .426), Digital Teaching Effectiveness (β = .151), and Student Learning Engagement (β = .162); competence-building initiatives will

have limited reach in schools that lack basic connectivity, electricity, or devices, so infrastructure investment should continue in parallel rather than being deprioritized.

Target pedagogical integration, not just device access, in teacher training design. Because Digital Teaching Effectiveness was the strongest predictor of engagement (β = .451) and partially mediated the competence–engagement relationship, training programs should explicitly build skills in interactive, technology-integrated instruction and digital assessment, rather than device operation alone.

Use the confirmed model to guide district-level resource allocation. Districts with comparatively higher reported Digital Readiness but lower Teacher Digital Competence are, per this model, better served by competence-building interventions; districts with low readiness on both dimensions should receive combined infrastructure-and-training packages.

Complete the H9 mediation test and extend the model with control variables before finalizing policy guidance. A dedicated PROCESS bootstrap analysis of the Digital Readiness → Digital Teaching Effectiveness → Student Learning Engagement pathway, and inclusion of the planned control variables (teacher age, experience, locality, internet access), would strengthen the evidentiary basis for the recommendations above.

Limitations

Several limitations should be considered when interpreting these findings. First, the cross-sectional design precludes causal inference; the significant regression and mediation pathways are consistent with, but do not definitively establish, the causal ordering proposed in the conceptual framework. Second, all constructs were measured through self-reported teacher survey responses, which raises the possibility of common method bias, particularly given that predictor and outcome measures were collected from the same respondents at the same time; the reported model fit statistics should be interpreted with this in mind. Third, the sample, while adequately powered (N = 500) and drawn from multiple rural districts, may not fully represent the diversity of rural school contexts across Sindh, limiting generalizability to districts or school types not well represented in the sampling frame. Fourth, the H9 mediation pathway (Digital Readiness → Digital Teaching Effectiveness → Student Learning Engagement) was not subjected to a dedicated bootstrapped mediation test in this analysis and should be treated as an open question rather than a confirmed finding. Finally, the planned control variables (teacher age, teaching experience, school locality, and internet access) were not incorporated into the regression and mediation models reported here; their inclusion in future analyses could refine the effect-size estimates presented above.

Significance of the Study

This study contributes both theoretically and practically. Theoretically, it extends TAM, TPACK/DigCompEdu, and Fredricks' engagement framework into an integrated, empirically tested mediation model in South Asian rural primary education — a context in which such integrated testing had previously been absent. Practically, its findings offer ORIC, HEC, and provincial education policymakers in Sindh an evidence-based basis for weighing investment between infrastructure (digital readiness) and teacher capacity-building (digital competence) to improve student engagement, directly supporting progress toward Sustainable Development Goal 4 (Quality Education).

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