RESEARCH ARTICLE

JENER Journal of Empirical and Non-Empirical Research
Volume 2, Issue 8, Page 945-955 | Article No. 105
DOI: 10.4898/jener.v2i8.a105
ISSN: 7895-9216
Journal homepage: https://jenerjournal.com
Journal email: editor@jenerjournal.com

JENER Journal
JENER Journal of Empirical and Non-Empirical Research

Digital Pedagogy Under Constraint: A Multilevel Mixed-Methods Study of Teacher Practice, School Readiness, and Learner Engagement in Public Schools of Batanes and Quirino, Philippines

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ARTICLE INFORMATION

Article history:
Published: August 2026

Keywords:
Digital Pedagogy
Resource-Constrained Schools
Teacher Digital Competence
Learner Engagement
Multilevel Analysis
Batanes
Quirino

ABSTRACT

Digital pedagogy in geographically isolated public schools depended on more than the presence of devices. This study examined how infrastructure, teacher capability, school support, and locally adapted teaching practices were associated with learner engagement in Batanes and Quirino, two contrasting provinces in Region II, Philippines. An explanatory sequential mixed-methods design covered 72 public schools, including 24 in Batanes and 48 in Quirino. Valid questionnaires were obtained from 414 teachers and 2,004 learners; school readiness audits were completed in all schools, 216 digitally supported lessons were observed, and 40 stakeholders participated in follow-up interviews. A four-domain Digital Pedagogy Practice Scale and a three-domain Learner Engagement Scale underwent ordinal confirmatory factor analysis. Omega reliability, design-conscious descriptive estimates, Welch comparisons, Holm correction, linear mixed-effects regression with restricted maximum likelihood and Kenward-Roger inference, intraclass correlations, marginal and conditional R-squared, and framework analysis were employed. School digital readiness averaged 63.8 of 100 (SD = 11.6); connectivity received the lowest domain score (M = 52.7), whereas governance and safeguarding received the highest (M = 73.6). Teacher digital-pedagogy practice averaged 3.42 of 5 (SD = 0.59), and learner engagement averaged 3.31 (SD = 0.64). In adjusted analysis, teacher technological-pedagogical-content knowledge (b = 0.41, 95% CI [0.32, 0.50]), each 10-point difference in school readiness (b = 0.09, 95% CI [0.04, 0.14]), sustained coaching (b = 0.14, 95% CI [0.05, 0.23]), and daily device access (b = 0.11, 95% CI [0.01, 0.21]) were positively associated with teacher practice. Teacher practice was also associated with learner engagement (b = 0.28, 95% CI [0.20, 0.35]) after learner and school covariates were controlled. Province was not independently associated with either outcome after readiness and access were included. Interviews showed that offline-first planning, device-sharing routines, peer coaching, cached content, and clear safeguarding procedures converted limited infrastructure into usable instruction. Cross-sectional associations did not establish causation. The findings supported a shift from hardware-only provision to reliability, instructional coaching, offline continuity, technical support, and equity monitoring.

1. Introduction

Digital transformation had become a stated priority in Philippine basic education. The Basic Education Development Plan 2030 and the MATATAG agenda had emphasized relevant curricula, better delivery of facilities and services, learner well-being, inclusion, and stronger support for teachers.[1] The Free Internet Access in Public Places Act had included public basic education institutions among the sites covered by the national connectivity program.[2] DepEd had also continued the Computerization Program, which sought to provide public schools with technologies that strengthened teaching and learning, including packages suitable for schools without conventional electricity.[3] These commitments created a clear policy direction, but they did not ensure that every device, connection, or platform was translated into instructionally valuable classroom use.

National conditions had remained uneven. The 2024 National Information and Communications Technology Household Survey reported that 48.8% of Philippine households had internet access at home and that 67.3% of individuals aged 10 years or older had used the internet.[7] The same survey showed that subscription cost remained a major barrier and that connection type differed widely. A World Bank assessment had likewise identified affordability, service quality, infrastructure, and longstanding analog practices as constraints on digital adoption in the Philippines.[8] These national indicators mattered for schooling because learners carried household-level access, device ownership, and connectivity limits into otherwise digitally supported lessons.

Government investments had accelerated. In 2025, DepEd reported delivery plans for 64,816 laptops and smart television packages while noting that 39,972 schools, or 69.3% of schools in its cited inventory, had below-ideal learner-to-device ratios.[4] Later connectivity initiatives had targeted last-mile and geographically isolated schools, including Chanarian Elementary School in Batanes.[5] The Department of Budget and Management subsequently released funding for school connectivity and free public internet, including support intended for 8,253 public schools.[6] These developments demonstrated momentum, yet they also made evaluation more important: the relevant outcome was not distribution alone but the quality, frequency, inclusiveness, and resilience of technology-supported teaching.

International evidence had cautioned against equating technology with learning. UNESCO had argued that education technology should be judged through relevance, equity, scalability, and sustainability, with learner interests and human interaction kept at the center.[9] Its Southeast Asia report had similarly described rapid digital expansion across highly varied national and local resource settings.[10] The OECD had distinguished simple digitization from deeper transformation of instructional processes and digital education ecosystems.[13] Thus, access remained necessary, but pedagogy, governance, teacher preparation, and institutional support determined whether access produced meaningful learning opportunities.

1.1 Digital pedagogy as situated professional practice

The technological-pedagogical-content knowledge framework had described effective technology integration as a situated interaction among what teachers taught, how they taught it, and which technologies served the instructional purpose.[14] A validated TPACK survey had provided an empirical basis for assessing these interrelated knowledge domains.[15] The framework was particularly relevant in constrained settings because the best available tool was not always the newest or most connected tool. A teacher who selected downloaded video, a shared tablet station, or an offline quiz for a specific concept could have demonstrated stronger digital pedagogy than a teacher who used an online platform without interaction or feedback.

Teacher competence frameworks had reinforced this instructional interpretation. UNESCO's ICT Competency Framework for Teachers had linked policy understanding, curriculum and assessment, pedagogy, digital skills, school organization, and professional learning.[11] DigCompEdu had organized educator competence around professional engagement, digital resources, teaching and learning, assessment, learner empowerment, and learners' digital competence.[12] Together, these frameworks suggested that digital pedagogy involved design, facilitation, assessment, adaptation, and responsible participation rather than technical operation alone.

Earlier research had separated first-order barriers, such as devices, connectivity, time, and technical support, from second-order barriers involving knowledge, confidence, beliefs, and culture.[16,17] A synthesis of teacher preparation evidence had further shown that authentic experiences, role examples, reflection, collaboration, and alignment across training components supported technology integration.[18] These findings implied that resource provision and professional learning should have been examined together. Where infrastructure was limited, local leadership and teacher collaboration could have either buffered or amplified the constraint.

Evidence on learning effects had remained heterogeneous. A second-order meta-analysis found a positive but variable average effect of technology on learning, with instructional conditions shaping the result.[19] A meta-analysis of mobile-device integration also found favorable average performance effects, while emphasizing differences across implementation designs.[20] In secondary mathematics and science, digital tools had produced larger benefits when teacher training accompanied use and when tools supplemented rather than replaced other instruction.[21] These results supported a careful evaluation of use quality, not a binary count of whether technology appeared in a classroom.

1.2 Equity, engagement, and resilience

Digital inequality had extended beyond physical access to differences in how technology was used and which outcomes it supported.[22] A shared device could still support discussion, peer explanation, and creation, whereas individual devices could remain confined to passive viewing. Equity therefore required attention to availability, reliability, instructional opportunity, accessibility, language, safeguarding, and the capacity to continue when internet or electricity failed.

Learner engagement provided a proximal outcome suited to a cross-sectional investigation of classroom practice. Engagement had been conceptualized as behavioral participation, emotional involvement, and cognitive investment.[23] Digitally supported instruction could have strengthened engagement through timely feedback, representation of difficult concepts, collaboration, choice, or creative production. It could also have weakened engagement when learners waited for scarce devices, watched long presentations, encountered inaccessible content, or lost instructional time to technical failure.

The distinction between planned online learning and emergency remote teaching also remained important.[24] Schools in Batanes and Quirino had not been evaluated as permanently online institutions. Their digital pedagogy was examined as a classroom and school practice that combined connected, offline, projected, mobile, printed, and interpersonal resources. Resilience referred to the ability to preserve the lesson objective when the preferred digital route failed, not merely the ability to restore an internet session.

1.3 Provincial context and research gap

Batanes and Quirino belonged to Region II but differed sharply in geography and scale. Official 2024 census results placed the population of Region II at 3,777,608, including approximately 19,000 residents in Batanes and 211,000 in Quirino.[26] Batanes consisted of six municipalities and 29 barangays across an island province, whereas Quirino consisted of six municipalities and 132 barangays.[26,27] The 2026 DepEd National Inventory Dashboard listed 27 schools in Batanes and 186 in Quirino, demonstrating the different scale of the two school systems.[28] The contrast created a useful comparative setting without implying that province itself caused differences in practice.

Batanes had long maintained a division-level Computerization Program page that recognized the need for appropriate technology packages in energized and unenergized public schools.[3] More recent national connectivity reporting had included a Batanes last-mile school among newly connected sites.[5] These initiatives confirmed that access conditions were changing. However, publicly available program reports did not explain how teachers combined devices, offline resources, classroom organization, assessment, and school support in ordinary lessons across Batanes and Quirino.

The study addressed that gap through linked evidence at the school, teacher, lesson, and learner levels. Implementation outcomes were treated as distinct from learner outcomes so that availability, feasibility, adoption, and sustainability could be interpreted separately from engagement.[25] The analysis asked which supports accompanied stronger practice and whether teacher practice remained associated with learner engagement after observed access differences were controlled.

1.4 Purpose, research questions, and hypotheses

The study evaluated digital pedagogy in resource-constrained public schools of Batanes and Quirino during School Year 2025-2026. It addressed six questions: (1) What levels of school digital readiness were observed across power, connectivity, devices, offline resources, technical support, and governance? (2) What digital-pedagogy practices were reported and observed? (3) What levels of learner engagement were reported? (4) Which teacher and school factors were associated with digital-pedagogy practice? (5) Was teacher digital-pedagogy practice associated with learner engagement after relevant covariates were controlled? and (6) How did stakeholders explain the principal successes, challenges, and adaptations?

Three directional hypotheses were specified before analysis. Higher teacher TPACK, stronger school readiness, sustained coaching, and daily device access were expected to accompany higher teacher-practice scores. Higher teacher-practice scores were expected to accompany higher learner engagement. Province differences were expected to attenuate after readiness, access, school level, and learner characteristics were included. Because assignment to digital-pedagogy conditions did not occur, every regression coefficient was interpreted as an adjusted association rather than a causal effect.

2. Methods

2.1 Design

An explanatory sequential mixed-methods design was employed. The quantitative phase combined a stratified school sample, a readiness audit, teacher and learner questionnaires, and structured classroom observation. The qualitative phase then selected contrasting schools on province, readiness, school level, and teacher-practice score to explain quantitative patterns. Integration occurred through connected sampling, interview questions built from initial results, a joint display, and an integrated interpretation.[40]

The quantitative component was cross-sectional at the main analytic point. School audits and surveys were completed within a six-week window, and classroom observations followed within four weeks. The design supported estimates of covariance among readiness, practice, and engagement but did not support claims about temporal sequence or intervention impact.

2.2 Setting and school sampling

The sampling frame included public elementary, integrated, junior high, and senior high schools under the Schools Divisions of Batanes and Quirino. Schools were stratified by province, school level, and accessibility. Twenty-four of the 27 schools listed for Batanes and 48 schools from the larger Quirino division were selected, producing 72 participating schools.[28] The Batanes allocation approached a division-wide census and preserved island and municipal variation; the Quirino allocation used probability-proportional-to-teacher-size selection within strata.

The final school sample included 46 elementary or primary-serving integrated schools and 26 secondary or secondary-serving integrated schools. Thirty schools met the study's prespecified remote-access criterion, which required either documented geographically isolated status or routine one-way travel exceeding 45 minutes from the municipal center under ordinary conditions. This analytic definition was used for stratification and was not presented as an official national classification.

2.3 Participants and sample size

Six teachers per school were randomly selected from faculty lists after representation by grade band was secured. Of 432 invited teachers, 414 returned usable questionnaires, for a response rate of 95.8%. Five learners were then randomly selected from one focal class taught by each responding teacher. Of 2,070 invited learners, 2,004 returned forms meeting the completion rule, for a valid response rate of 96.8%. The learner sample covered upper-elementary and secondary grade bands because the engagement items required independent reading.

Three teachers per school were selected from the survey respondents for one lesson observation, yielding 216 observations. Twelve contrast schools supplied the qualitative sample: 12 school heads, 12 teachers, eight learners, and eight parents or guardians, for 40 interviews. Selection sought information-rich variation in readiness and practice. Sample adequacy for the qualitative phase was reviewed through aim specificity, stakeholder diversity, dialogue quality, established theory, and cross-case analytic needs, consistent with information-power guidance.[39]

The highest-level sample contained 72 schools, above the prespecified minimum of 60 clusters. With an average of 5.75 responding teachers per school and a null school intraclass correlation of 0.18 for the teacher-practice outcome, the achieved design had an approximate effective teacher sample of 223. The study therefore had sufficient information for the limited set of prespecified fixed effects, while Kenward-Roger inference was retained to reduce finite-cluster bias.[33,34]

Table 1. Analytic sample by province and data source

Data source	Batanes	Quirino	Total
Participating schools	24	48	72
Valid teacher questionnaires	138	276	414
Valid learner questionnaires	666	1,338	2,004
Observed lessons	72	144	216
School readiness audits	24	48	72
Qualitative participants	16	24	40

2.4 Measures

2.4.1 School Digital Readiness Audit

The School Digital Readiness Audit contained 24 indicators across six domains: power reliability, connectivity, device sufficiency and usability, offline learning resources, technical support and maintenance, and governance and safeguarding. Evidence included service logs, device inventories, maintenance records, content repositories, access schedules, and school protocols. Each indicator was scored from 0 to 4 using anchored criteria. Domain scores were converted to 0-100 scales, and the total readiness score was the equally weighted mean of the six domains. Equal weighting preserved transparency and prevented the most item-rich domain from dominating the index.

A second auditor independently scored 18 schools. The two-way random, absolute-agreement intraclass correlation for the total score was 0.86 (95% CI [0.70, 0.94]); weighted kappa across ordinal indicators ranged from 0.72 to 0.88. Agreement statistics were selected because percent agreement alone did not account for chance concordance.[32]

2.4.2 Digital Pedagogy Practice Scale

The teacher instrument included 20 five-point frequency items organized into instructional design, interaction and collaboration, assessment and feedback, and inclusion and adaptation. Item content drew from TPACK, UNESCO ICT-CFT, and DigCompEdu, then was rewritten for Philippine public-school classroom conditions.[11,12,14,15] Responses ranged from 1 (never) to 5 (almost every lesson). The total score was the mean of completed items when at least 80% were answered; higher scores represented more frequent instructionally purposeful practice.

A separate 16-item TPACK measure captured technology, pedagogy, content, and intersecting knowledge on a five-point confidence scale. It served as a predictor rather than a component of the outcome. The distinction reduced criterion contamination: confidence in professional knowledge did not automatically count as frequent classroom practice.

2.4.3 Learner Engagement Scale

The learner instrument contained 12 five-point items across behavioral participation, emotional involvement, and cognitive investment, consistent with the multidimensional engagement literature.[23] Items asked about the focal teacher's class during the preceding month. The score was the mean when at least 10 items were completed. Home internet availability, usual device-sharing condition, grade band, age, and sex were recorded as covariates.

2.4.4 Classroom Observation Protocol

Observers recorded the lesson objective, technology used, online or offline route, device organization, learner participation, formative assessment, feedback, accessibility supports, and contingency actions. Seven focal practices were coded as present or absent. A 12-indicator quality rubric produced a 1-4 mean score for purpose alignment, learner activity, feedback, differentiation, and continuity. Forty-four lessons were independently double-rated. The quality-score intraclass correlation was 0.84 (95% CI [0.73, 0.91]), and indicator kappa ranged from 0.71 to 0.86.

2.4.5 Interview guides

Semistructured guides explored lesson planning, resource allocation, device-sharing routines, connectivity interruptions, offline alternatives, professional learning, technical support, learner participation, family access, accessibility, privacy, and sustainability. School-specific prompts were generated from the audit and survey profiles, but interviewers did not reveal comparative ranks to participants.

2.5 Instrument development and validation

Seven experts in educational technology, curriculum, rural education, measurement, and public-school administration reviewed the instruments. Item-level content-validity indexes ranged from 0.86 to 1.00, and scale-average indexes were 0.94 for the teacher scale and 0.96 for the learner scale. Items below the panel's clarity threshold were revised before administration. The use of item and scale content-validity indexes followed published recommendations for expert review.[29]

Because response options were ordinal, confirmatory factor analyses used the weighted least-squares mean- and variance-adjusted estimator with polychoric correlations.[30] The prespecified teacher structure contained four correlated factors and one higher-order practice factor. The learner structure contained three correlated factors and one higher-order engagement factor. Fit was judged through the comparative fit index, Tucker-Lewis index, root mean square error of approximation with 90% confidence interval, and standardized root mean square residual. Omega, rather than alpha alone, was used for score reliability because it did not require equal item loadings.[31]

A pilot administration in two non-sampled public schools tested comprehension, timing, and field procedures. Pilot responses were not included in the main analysis. No items were removed after examination of the main outcome associations; the scoring rules and factor structures remained fixed before regression.

2.6 Data collection

Trained field teams completed school audits before survey administration. Teacher forms were completed individually, and learner forms were administered in small groups with standardized instructions. Unique study codes linked learners to focal teachers and teachers to schools. Identifying information was kept outside analytic files. Observers received two days of calibration and reached the field threshold before independent scoring.

Qualitative interviews lasted 32-58 minutes, were audio recorded with permission, transcribed, checked against recordings, and de-identified. Interviews in Filipino or a local language were translated into English for the reporting matrix after bilingual checking. Reflexive memos documented the interviewer's role, provisional explanations, contradictory cases, and decisions that changed the analytic framework.

2.7 Statistical treatment

Descriptive statistics matched the scale of each variable. Means and standard deviations summarized approximately symmetric composites; medians and interquartile ranges summarized skewed counts; frequencies and percentages summarized categories. Ninety-five percent confidence intervals accompanied main estimates. Province comparisons for school-level readiness used Welch's t test because school counts and variances differed. Teacher and learner descriptive comparisons used 2,000 school-cluster bootstrap resamples. Holm's sequential procedure controlled familywise error across the six readiness-domain province comparisons.[37]

The teacher-practice analysis used a two-level linear mixed-effects regression with a random school intercept. Prespecified fixed effects were TPACK, readiness per 10 points, sustained coaching, daily device access, reliable school internet, teaching experience per 10 years, school level, and province. Continuous predictors were centered at their grand means. Restricted maximum likelihood and Kenward-Roger degrees of freedom were used because the highest level contained 72 schools.[33,34] Unstandardized coefficients, standard errors, 95% confidence intervals, and exact p values were reported.

The learner-engagement analysis used a three-level linear mixed-effects regression with learners nested within teachers and teachers nested within schools. Fixed effects were teacher digital-pedagogy score, readiness per 10 points, home internet availability, frequent device sharing, grade band, sex, and province. The random structure contained teacher and school intercepts. Marginal R-squared summarized variance associated with fixed effects, whereas conditional R-squared summarized fixed and random components.[35] Null and adjusted intraclass correlations were reported at teacher and school levels.

Item nonresponse ranged from 0.2% to 1.8%. Person-mean scoring was applied only when the prespecified completion threshold was met; otherwise the form was excluded from that scale. Required regression covariates were complete after field verification. A sensitivity analysis used 25 chained-equation imputations before score construction and produced the same decisions and materially similar coefficient estimates.[36] Residual plots were examined for linearity, constant variance, influential schools, and approximate normality. Variance-inflation factors were below 2.2. Robustness checks removed one school at a time and repeated the learner analysis with school-cluster-robust standard errors.

The correlation between teacher self-report and observation quality in the 216-lesson subsample was reported as convergent evidence, not as proof of criterion validity. Primary hypotheses used two-sided alpha = .05. The six readiness-domain province tests alone received multiplicity correction because they formed one descriptive family; prespecified regression coefficients were accompanied by intervals and interpreted by magnitude and uncertainty rather than p-value counting.

2.8 Qualitative analysis and integration

Framework analysis proceeded through familiarization, initial coding, development of an analytic matrix, indexing, charting by case and stakeholder group, and interpretation.[38] Two analysts independently coded six transcripts, reconciled definitions, and then applied the agreed framework while preserving space for new codes. Credibility was strengthened through negative-case review, comparison across roles and provinces, transcript-to-matrix checks, and an audit trail of coding decisions.

Integration compared quantitative findings with qualitative explanations in a joint display. Findings were classified as convergent when both strands supported the same interpretation, elaborative when interviews explained a quantitative pattern, and divergent when stakeholder accounts contradicted the observed pattern. No quotation was treated as a prevalence estimate.

3. Results

3.1 Participant and school profile

The 414 teachers had a mean age of 39.2 years (SD = 8.7) and a median of 11 years of teaching experience (IQR = 6-18). Women constituted 77.5% of the teacher sample, reflecting the composition of the participating faculty lists. Fifty-nine percent taught in elementary or primary-serving classes. Eighty-six percent had completed at least one digital-tool orientation during the preceding two years, but only 42.5% had participated in sustained coaching that included follow-up observation, peer demonstration, or feedback.

Among the 2,004 learners, 33.2% came from Batanes and 66.8% from Quirino. Upper-elementary learners represented 54.6%, and secondary learners represented 45.4%. Home internet was available to 58.9%; 36.7% reported that they frequently shared the device used for schoolwork with another household member. The school sample included 30 remote-access schools and 42 other schools.

Table 2. Selected teacher, learner, and school characteristics

Characteristic	Batanes	Quirino	Overall
Teacher age, M (SD)	40.1 (8.6)	38.8 (8.8)	39.2 (8.7)
Teaching experience, median (IQR)	12 (7-19)	10 (6-17)	11 (6-18)
Sustained coaching, n (%)	51 (37.0)	125 (45.3)	176 (42.5)
Daily teacher device access, n (%)	108 (78.3)	234 (84.8)	342 (82.6)
Reliable internet during school day, n (%)	55 (39.9)	151 (54.7)	206 (49.8)
Learners with home internet, n (%)	356 (53.5)	825 (61.7)	1,181 (58.9)
Remote-access schools, n (%)	16 (66.7)	14 (29.2)	30 (41.7)

3.2 Measurement evidence

The four-factor teacher-practice structure fit the ordinal data well: comparative fit index = 0.957, Tucker-Lewis index = 0.951, root mean square error of approximation = 0.044 (90% CI [0.036, 0.052]), and standardized root mean square residual = 0.049. Standardized first-order loadings ranged from 0.61 to 0.84. Omega was 0.91 for the total score and ranged from 0.83 to 0.89 across the four domains. The three-factor learner-engagement structure also fit well: comparative fit index = 0.965, Tucker-Lewis index = 0.959, root mean square error of approximation = 0.041 (90% CI [0.036, 0.046]), and standardized root mean square residual = 0.038. Standardized loadings ranged from 0.64 to 0.82, and total-score omega was 0.88. The prespecified structures were retained without data-driven item deletion. In the observation subsample, the teacher-practice self-report correlated moderately with observed digital-pedagogy quality ($r = 0.46$, 95% CI [0.35, 0.56], $p < .001$). The association supported convergent interpretation while also showing that self-report and observation captured nonidentical information.

Table 3. Confirmatory factor and reliability results

Scale	Items	CFI	TLI	RMSEA (90% CI)	SRMR	Omega
Digital Pedagogy Practice	20	.957	.951	.044 (.036-.052)	.049	.91
Learner Engagement	12	.965	.959	.041 (.036-.046)	.038	.88

3.3 School digital readiness

The overall readiness score was 63.8 of 100 (SD = 11.6). Governance and safeguarding received the highest mean (73.6), followed by offline learning resources (71.9) and power reliability (66.2). Connectivity received the lowest mean (52.7), followed by device sufficiency and usability (57.4). These scores indicated that participating schools had developed policy and offline routines faster than stable, sufficient technical capacity.

Batanes schools had a lower total readiness mean than Quirino schools, 58.4 versus 66.5. The mean difference was -8.1 points (95% CI [-13.4, -2.8], Welch $p = .003$; Hedges $g = -0.73$). After Holm correction, the province differences remained statistically distinguishable for connectivity and device sufficiency, but not for offline resources. Province described a bundle of geographic and system conditions; the comparison did not identify a provincial causal mechanism.

Table 4. School digital readiness by domain and province

Readiness domain (0-100)	Batanes M (SD)	Quirino M (SD)	Overall M	Difference	Holm p
Power reliability	62.4 (14.1)	68.1 (13.0)	66.2	-5.7	.146
Connectivity	44.9 (12.7)	56.6 (14.0)	52.7	-11.7	.006
Device sufficiency and usability	52.0 (12.0)	60.1 (12.7)	57.4	-8.1	.041
Offline learning resources	74.0 (10.3)	70.9 (11.6)	71.9	3.1	.438
Technical support and maintenance	56.2 (13.4)	63.1 (12.8)	60.8	-6.9	.092
Governance and safeguarding	69.0 (11.0)	75.9 (10.1)	73.6	-6.9	.064
Total readiness	58.4 (10.2)	66.5 (11.4)	63.8	-8.1	.003*

3.4 Teacher digital-pedagogy practices

The total teacher-practice mean was 3.42 of 5 (SD = 0.59). Instructional design received the highest domain mean (3.66), whereas assessment and feedback received the lowest (3.29). The Batanes mean was 3.31 (SD = 0.60), and the Quirino mean was 3.48 (SD = 0.58). The unadjusted province difference was 0.17 points (95% school-cluster bootstrap CI [0.05, 0.29]).

Teacher access was more common than stable classroom connectivity. Daily access to a usable teacher device was reported by 82.6%, and access to organized offline resources was reported by 74.2%, but reliable internet during the school day was reported by 49.8%. Sustained coaching reached 42.5%, even though 86.0% had attended at least one orientation. The gap between one-time exposure and ongoing support was therefore larger than the gap in basic teacher device access.

Table 5. Digital-pedagogy practice domains

Domain (1-5)	Items	Batanes M (SD)	Quirino M (SD)	Overall M (SD)
Instructional design	5	3.55 (0.63)	3.72 (0.57)	3.66 (0.60)
Interaction and collaboration	5	3.26 (0.68)	3.43 (0.63)	3.37 (0.65)
Assessment and feedback	5	3.18 (0.65)	3.35 (0.61)	3.29 (0.63)
Inclusion and adaptation	5	3.26 (0.66)	3.40 (0.61)	3.35 (0.63)
Total practice	20	3.31 (0.60)	3.48 (0.58)	3.42 (0.59)

3.5 Observed lesson patterns

Projected or multimedia representation appeared in 68.1% of observed lessons, and preloaded or offline digital content appeared in 61.1%. A digitally supported formative check appeared in 54.2%, and timely teacher or system feedback appeared in 45.4%. More demanding learner-centered uses were less common: digitally supported collaboration appeared in 37.0%, adaptive or differentiated digital tasks in 31.9%, and learner-created digital products in 28.2%.

The observed quality score averaged 3.16 of 4 (SD = 0.51). Lessons with learner creation or collaborative problem solving had higher mean quality than display-only lessons, 3.43 versus 2.89, for a difference of 0.54 (95% school-cluster bootstrap CI [0.38, 0.70]). This comparison was descriptive because teachers had not been randomly allocated to lesson designs.

Table 6. Focal practices in 216 observed lessons

Observed practice	n	% of lessons
Projected or multimedia representation	147	68.1
Preloaded or offline digital content	132	61.1
Digitally supported formative check	117	54.2

Observed practice	n	% of lessons
Timely teacher or system feedback	98	45.4
Digitally supported collaboration	80	37.0
Adaptive or differentiated digital task	69	31.9
Learner-created digital product	61	28.2

3.6 Factors associated with teacher practice

The null school intraclass correlation for teacher practice was 0.18, indicating that 18% of total variance lay between schools before predictors were added. In the adjusted regression, TPACK had the largest association: each one-point difference on the five-point scale accompanied a 0.41-point difference in practice (95% CI [0.32, 0.50], $p < .001$). Each 10-point readiness difference accompanied a 0.09-point practice difference (95% CI [0.04, 0.14], $p < .001$). Sustained coaching and daily device access also retained positive associations. Reliable internet during the school day had a positive but imprecise adjusted coefficient, $b = 0.06$ (95% CI [-0.03, 0.15], $p = .180$). This result did not show that connectivity was unimportant; it indicated that, within the observed covariate set, the independent mean difference was uncertain after the broader readiness score and offline adaptations were included. Province was likewise attenuated to $b = -0.04$ (95% CI [-0.16, 0.08], $p = .520$).

Fixed effects accounted for a marginal R-squared of 0.52, and fixed plus random effects accounted for a conditional R-squared of 0.61. The adjusted school intraclass correlation declined to 0.09. No single-school deletion changed the sign of a primary coefficient or moved the TPACK, readiness, coaching, or device-access interval across zero.

Table 7. Two-level mixed-effects regression for teacher digital-pedagogy practice (n = 414 teachers; 72 schools)

Predictor	b	SE	95% CI	p
TPACK score, per 1 point	0.41	0.044	0.32, 0.50	<.001
School readiness, per 10 points	0.09	0.025	0.04, 0.14	<.001
Sustained coaching, yes vs no	0.14	0.048	0.05, 0.23	.004
Daily teacher device access, yes vs no	0.11	0.052	0.01, 0.21	.032
Reliable school internet, yes vs no	0.06	0.045	-0.03, 0.15	.180
Teaching experience, per 10 years	-0.02	0.018	-0.06, 0.02	.300
Secondary-serving vs primary-serving	0.03	0.047	-0.06, 0.12	.530
Batanes vs Quirino	-0.04	0.061	-0.16, 0.08	.520

3.7 Learner engagement and its correlates

Learner engagement averaged 3.31 of 5 (SD = 0.64). The Batanes mean was 3.22 (SD = 0.65), and the Quirino mean was 3.36 (SD = 0.63). Behavioral participation had the highest overall mean (3.43), followed by emotional involvement (3.31) and cognitive investment (3.19).

In the adjusted three-level analysis, each one-point difference in teacher digital-pedagogy practice accompanied a 0.28-point learner-engagement difference (95% CI [0.20, 0.35], $p < .001$). Each 10-point readiness difference accompanied a 0.05-point difference (95% CI [0.01, 0.08], $p = .008$). Home internet availability had a positive coefficient, whereas frequent sharing of the usual schoolwork device had a negative coefficient. Secondary grade band had a small negative adjusted coefficient.

Province was not independently associated with engagement after teacher practice, readiness, and learner access were included, $b = -0.03$ (95% CI [-0.10, 0.04], $p = .410$). Fixed effects accounted for a marginal R-squared of 0.27, and the full random-intercept structure produced a conditional R-squared of 0.39. Null intraclass correlations were 0.14 at teacher level and 0.08 at school level; adjusted values were 0.09 and 0.05, respectively.

Table 8. Three-level mixed-effects regression for learner engagement (n = 2,004 learners; 414 teachers; 72 schools)

Predictor	b	SE	95% CI	p
Teacher digital-pedagogy score, per 1 point	0.28	0.038	0.20, 0.35	<.001
School readiness, per 10 points	0.05	0.018	0.01, 0.08	.008
Home internet available, yes vs no	0.09	0.029	0.03, 0.15	.003
Frequent device sharing, yes vs no	-0.08	0.027	-0.13, -0.03	.004
Secondary vs upper-elementary grade band	-0.07	0.031	-0.13, -0.01	.024
Female vs male	0.04	0.024	-0.01, 0.09	.110
Batanes vs Quirino	-0.03	0.036	-0.10, 0.04	.410

3.8 Stakeholder explanations

3.8.1 Offline-first orchestration preserved the lesson objective

Teachers in both provinces described planning two routes for the same objective: a connected route when bandwidth held and an offline route using downloaded media, local servers, screenshots, printed response sheets, or teacher-prepared files. This practice was strongest in schools with organized repositories and clear responsibility for updating content. Internet instability still consumed time, but it did not automatically end the learning task.

The qualitative account explained why offline-resource readiness was relatively high and why reliable internet lost precision in the adjusted teacher-practice regression. Connectivity remained a foundational condition, but teachers had partially buffered short interruptions through preparation. Longer outages, software authentication requirements, and upload-heavy tasks were less easily buffered.

3.8.2 Shared devices changed the social organization of learning

Device scarcity produced two contrasting patterns. Some lessons became teacher-controlled displays in which learners watched but rarely manipulated information. Other teachers organized pairs, rotating stations, assigned device roles, peer checking, and group products. Learners described higher involvement when waiting time was short and every group member had a visible responsibility. These accounts aligned with the observation result: learner creation and collaboration accompanied higher quality scores than display-only use. They also clarified the negative learner-level coefficient for frequent household device sharing. Classroom routines could distribute participation during school, but they did not remove unequal opportunity to continue tasks at home.

3.8.3 Coaching made adaptation routine

Teachers distinguished short orientations from repeated opportunities to see a colleague's lesson, try a strategy, receive feedback, and revise. Peer demonstrations were valued because they used the same devices, bandwidth limits, curriculum materials, and class sizes. School heads described protected collaborative planning time as more sustainable than sending isolated teachers to tool-centered seminars.

The theme elaborated the positive coaching coefficient. Coaching appeared to strengthen both technical fluency and instructional decision making, especially selection of lower-bandwidth alternatives, formative checks, and device-sharing structures.

3.8.4 Connectivity behaved as a scheduling condition

Participants rarely described internet as simply present or absent. Performance changed by time of day, weather, location on campus, simultaneous users, and the bandwidth demand of the selected platform. Teachers scheduled downloads before class, delayed synchronization, compressed files, or moved high-demand tasks to a shorter window. School heads treated recurring subscription cost and equipment replacement as planning concerns rather than one-time procurement decisions.

Batanes participants emphasized weather and inter-island logistics, while Quirino participants more often described distance, terrain, and service variation across municipalities. The common mechanism was reliability: instructional planning improved when teachers knew what capacity would be available and who would respond when it failed.

3.8.5 Safeguarding and workload shaped sustainability

School heads reported progress in account management, acceptable-use rules, and parent communication, consistent with the relatively high governance score. Teachers nevertheless described additional work from preparing duplicate routes, managing files, troubleshooting devices, documenting use, and monitoring learner accounts. Parents supported digital activities when tasks were clear and low cost, but resisted requirements that depended on new data purchases or continuous home access.

Stakeholders therefore defined sustainability as a manageable routine with protected time, technical support, affordable connectivity, replacement plans, and privacy safeguards. Enthusiasm alone had not been treated as a durable implementation resource.

Table 9. Mixed-methods joint display

Quantitative finding	Qualitative explanation	Integrated inference
Connectivity was the lowest readiness domain.	Capacity varied by time, weather, campus location, and concurrent use.	Reliability and predictability mattered more than a yes/no connection label.
Offline resources scored relatively high.	Teachers cached files and prepared low-bandwidth alternatives.	Offline continuity buffered short failures but did not replace adequate connectivity.
Coaching accompanied stronger teacher practice.	Repeated demonstration, trial, feedback, and peer planning were valued.	Job-embedded coaching supported adaptation better than one-time orientation alone.
Learner-centered observed uses had higher quality.	Roles, stations, and group products reduced passive waiting around shared devices.	Device scarcity did not determine pedagogy; classroom organization changed its effect.
Province coefficients attenuated after adjustment.	Both provinces reported different surface constraints but similar adaptation mechanisms.	Readiness and local routines explained more variation than the province label alone.

4. Discussion

4.1 Principal findings

The study found moderate digital readiness, moderately frequent digital-pedagogy practice, and moderate learner engagement across the participating schools. The principal constraint was not complete absence of technology. It was the uneven reliability of connectivity, devices, maintenance, and support relative to the instructional demands placed on schools. Governance and offline resources had developed further than technical capacity, suggesting that schools had created local routines while continuing to work within material limits.

Teacher TPACK, school readiness, sustained coaching, and daily device access had independent positive associations with practice. These findings supported a complementary rather than substitutive account of digital pedagogy. Teacher knowledge did not eliminate the need for infrastructure, and infrastructure did not eliminate the need for instructional judgment. The results aligned with TPACK and with evidence that knowledge, confidence, beliefs, culture, authentic preparation, and school conditions intersected in technology use.[14,17,18]

Teacher practice was associated with learner engagement after measured access and context were controlled. The magnitude was meaningful but not deterministic: a full one-point practice difference accompanied a 0.28-point engagement difference on a five-point scale. Considerable learner, teacher, and school variance remained. The result therefore supported digital pedagogy as one part of an engagement ecology rather than a standalone solution.

4.2 From access to instructional reliability

The readiness profile refined the usual access discussion. Connectivity received the lowest score, but internet availability had an imprecise coefficient after the broader readiness index entered the teacher analysis. Qualitative evidence showed why: teachers responded to intermittent service through cached content, delayed synchronization, compressed files, and parallel offline tasks. This pattern did not diminish the importance of connectivity. It indicated that the educational value of connectivity was conditioned by reliability, bandwidth demand, maintenance, planning, and the availability of a feasible fallback.

UNESCO had identified access, governance, and teacher preparation as system conditions for technology to serve education.[9] The current findings showed those conditions operating at school level. A device became instructionally available only when it worked, carried appropriate content, could be scheduled equitably, and was supported by a teacher who could redesign the activity. This interpretation also matched the OECD distinction between installing digital components and transforming educational processes.[13]

National connectivity and equipment programs remained necessary. Official Philippine reports had documented large learner-to-device gaps and continuing last-mile connectivity work.[4–6] The findings suggested that program monitoring should have added measures of uptime, usable device-days, classroom bandwidth, repair turnaround, offline-content currency, and instructional use quality. Delivery counts alone could not reveal whether schools received a dependable learning service.

4.3 Teacher learning and school organization

Sustained coaching had a positive adjusted association even after TPACK and readiness were controlled. Participants attributed its value to repeated practice in the actual school environment. This finding was consistent with evidence that teacher training strengthened the learning benefits of digital tools and that preparation worked best when it included authentic use, collaboration, reflection, and role examples.[18,21]

One-time orientation remained useful for awareness and basic operation, but it had not supplied the iterative support required for lesson redesign. A practical coaching cycle would have included joint planning, a brief demonstration, classroom use, evidence review, and revision. The focal problem should have been pedagogical - such as formative feedback with shared devices - rather than tool-centered - such as completing every menu in an application.

Leadership mattered through time, routines, and norms. Schools with repositories, named technical contacts, device schedules, and collaborative planning reduced the individual burden on teachers. These supports represented inner-setting and implementation-process conditions that helped technology enter routine practice.[25] They also explained why between-school variance persisted after individual teacher characteristics were included.

4.4 Engagement, equity, and the quality of use

The study's engagement findings supported the distinction among behavioral, emotional, and cognitive involvement.[23] Multimedia representation could attract attention, but higher observed quality appeared when learners discussed, created, received feedback, or made decisions. Passive display was not inherently poor, particularly when it clarified an inaccessible concept, yet it offered fewer opportunities to reveal thinking or distribute participation.

Frequent device sharing had a negative learner-level association after other covariates were controlled. Interviews showed that sharing was not a single experience. Structured pairs and stations could have supported peer explanation, whereas unstructured waiting reduced access to the task. At home, sharing often meant delayed work and restricted practice time. Equity monitoring should therefore have examined who operated the device, who waited, who received feedback, and which tasks required access beyond school.

The findings echoed digital-inequality research that had moved from ownership to differences in use and outcome.[22] They also supported the UNESCO position that technology decisions should have been appropriate, equitable, evidence-based, and sustainable.[9,10] In Batanes and Quirino, equitable digital pedagogy would have combined shared-school access, offline continuity, accessible formats, culturally and linguistically appropriate content, and limits on required household spending.

4.5 Interpreting the province comparison

Batanes had lower unadjusted readiness and practice means, but province did not retain an independent association after readiness, coaching, access, and school level were included. This attenuation supported the prespecified hypothesis and discouraged a deficit interpretation of either province. Province captured many conditions at once, including school-system scale, geography, service markets, travel, and exposure to weather. The analysis suggested that actionable school and teacher conditions were more informative than the provincial label by itself.

The qualitative evidence nevertheless preserved contextual differences. Batanes participants emphasized inter-island logistics and weather-sensitive continuity; Quirino participants emphasized terrain, distance, and within-province service variation. A common strategy could therefore have specified minimum outcomes - reliable access, usable devices, current offline materials, response time, and equitable participation - while allowing each division to choose context-responsive delivery arrangements.

5. Recommendations

- Adopt a minimum digital-learning service standard: DepEd regional and division offices should have specified minimum thresholds for classroom uptime, usable device availability, repair turnaround, offline access, safeguarding, and support response. Schools could then have used the most suitable technical mix for island, mountain, remote, and central settings.
- Fund coaching as an implementation component: Professional development should have moved beyond one-time orientation. A recurring cycle of collaborative planning, peer demonstration, classroom use, evidence review, and revision should have focused on formative assessment, collaboration, accessibility, and low-bandwidth design.
- Require offline continuity plans: Each school should have maintained current offline repositories, file-naming and update rules, printable alternatives, local access instructions, and lesson contingencies. Offline provision should have served as continuity support, not as justification for leaving connectivity gaps unresolved.
- Monitor the quality and equity of use: School dashboards should have tracked which learners operated devices, waited, collaborated, created products, received feedback, and required home access. Results should have been disaggregated by grade band, sex, disability where safely available, home access, remote-access status, and province.

- Strengthen maintenance and lifecycle financing: Procurement plans should have included inventory accuracy, preventive maintenance, replacement schedules, battery and peripheral costs, license renewal, connectivity subscriptions, and named technical support. Usable device-days should have been monitored alongside delivery counts.
- Protect learner data and preserve human interaction: Schools should have applied data minimization, access control, retention limits, secure accounts, parent communication, and incident procedures consistent with Philippine privacy law.[42] Digital activities should have supported teacher-learner interaction rather than displaced explanation, discussion, and care.
- Commission a longitudinal effectiveness study: A follow-up study should have used repeated classroom observations, curriculum-aligned achievement measures, attendance, cost records, and staggered introduction of coaching or reliability supports. That design would have permitted stronger estimates of change and cost-effectiveness than the current cross-sectional study.

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