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Scaling Early Childhood Digital Practices Through a Design-Based Implementation Research Model in Rural Ecosystems

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ABSTRACT

This study examines how a design-based implementation research (DBIR) approach can accelerate developmentally appropriate digitalization in early childhood education within a rural village ecosystem. We co-designed, piloted, and iteratively refined a practice-proximal package, professional learning and coaching, a contextualized digital lesson bank, implementation tools (rubrics/SOPs), and organizational supports, delivered through a stepped-wedge rollout across six ECE centers (310 children; 34 staff). Mixed methods integrated repeated surveys/logs, structured classroom observations and artefact audits, and interviews/FGDs; instruments covered teacher outcomes, classroom processes, center-level implementation outcomes, and system supports. Quantitatively (n=18 teachers), teachers strongly endorsed play-based pedagogy and age-appropriate management and reported high confidence to blend traditional–digital approaches, while routine device/app use and simple media creation were lower, indicating an enactment fluency gap. Qualitatively, key barriers were limited devices/media, uneven digital skills, and device-related classroom management; children's engagement was predominantly positive. Triangulation suggests two proximal mechanisms, motivation and procedural clarity, by which coaching and SOPs (rotation/transition) convert enthusiasm into on-task behavior. Findings yield a feasible pathway for scale: prioritize shared-device solutions and offlineable media, intensify practice-based coaching on two workflow "kernels," and institutionalize leadership-backed routines. Future work will test dose–response and moderation using longitudinal mixed-effects models and center-level interrupted time series to assess sustainment and generalizability.

Keywords: *Design-Based Implementation Research; Early Childhood Digitalization; Teacher Practice; Implementation Outcomes; Rural Education*

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INTRODUCTION

Digital technologies have become routine artefacts in early childhood education (ECE), yet their value depends less on mere access to devices and more on teachers' capacity to orchestrate developmentally appropriate digital–nondigital activity structures in real classrooms. Recent state-of-the-art syntheses converge on a central message, digital pedagogy, the principled integration of tools, content, and pedagogy, is the primary lever for quality (rather than technology per se). A review-of-reviews on the Technological Pedagogical Content Knowledge (TPACK) literature shows that, despite abundant studies, conceptual clarity and robust links between teacher knowledge and enacted practice remain uneven, calling for designs that trace observable change in classrooms (Schmid et al., 2024). Similarly, a 2024 systematic review on digital play concludes that affordances such as interactivity and meaning-making are realized when teachers purposefully design hybrid routines rather than substituting screens for play (Chu et al., 2024). Together, these syntheses argue for practice-proximal models that help teachers plan, enact, and assess digital learning aligned with developmentally appropriate practice (DAP).

Post-pandemic evidence also warns that digitalization can widen inequities where implementation barriers persist, particularly in rural or low-resource systems. A contemporary review documents how remote schooling amplified the digital divide and educational inequities for marginalized youth, highlighting that disparities span not only access but also capability and outcomes (Golden et al., 2023). In low and middle-income countries (LMICs), a systematic review of technology-mediated teacher professional development (TPD) finds that sustained, practice-proximal, and context-responsive designs show the most promise, yet such features are infrequent and often undermined by weak leadership and infrastructure (Hennessy et al., 2019). These findings underscore a dual imperative for rural village ecosystems, strengthen teacher practice *and* the organizational conditions, leadership routines, resource flows, and peer support, that enable adoption and sustainability.

Despite these advances, much ECE digitalization research remains tool-centric or confined to single-site pilots, yielding limited insight into how to implement at scale with fidelity and local adaptation. Implementation science helps bridge this gap by distinguishing learner/service outcomes from implementation outcomes (acceptability, adoption, appropriateness, feasibility, fidelity, penetration, cost, sustainability) and by urging their routine assessment alongside effectiveness (Proctor et al., 2023). Measurement work further catalogues instruments for these outcomes and encourages stronger psychometrics and reporting standards (Mettert et al., 2020). Yet within ECE, studies that iteratively refine an intervention while examining implementation outcomes across multiple centres remain comparatively scarce.

Design-Based Implementation Research (DBIR) is well suited to this challenge because it explicitly couples iterative co-design with attention to organizational and policy conditions for spread and sustainability. Emerging work demonstrates the feasibility of combining DBIR with rigorous causal designs to optimize interventions in situ while estimating their effects (Begolli et al., 2024). In ECE, where pedagogies are play-centred and community-embedded, DBIR offers a principled way to co-design contextualized lesson

plans, practice rubrics, and leadership supports that fit local realities, while generating actionable knowledge about what enables uptake across centres.

Building on this literature, we identify three gaps the present study addresses. First, there is limited evidence tracing the pathway from teacher professional learning to observable, rubric-rated changes in digital pedagogy under real-world resource constraints. Second, few studies in rural village contexts jointly examine practice change and implementation outcomes over time as programs expand across centres. Third, there is a methodological gap in demonstrating scale-readiness through iterative packaging (manuals, SOPs, contextualized Lesson Plan exemplars) informed by mixed-methods data from teachers, leaders, and caregivers. Our novelty lies in deploying a DBIR approach that integrates (a) co-design of a practice-proximal digitalization package, (b) iterative refinement across cohorts, and (c) concurrent assessment of implementation outcomes, yielding both a replication kit and explanatory accounts of what drives adoption and persistence in a village ecosystem (cf. Proctor et al., 2023; Hennessy et al., 2022).

The study investigates whether a co-designed digital pedagogy program improves (1) teachers' digital pedagogical competence (planning, enactment, documentation/assessment, engagement) and (2)) DAP-aligned digital integration in classrooms, and (3) whether stronger implementation supports (leadership practices, peer coaching, infrastructure) moderate these effects across centres. Guided by DBIR, we implement multi-cycle co-design, pilot, and refinement while tracking implementation outcomes (acceptability, appropriateness, feasibility, adoption, fidelity, early sustainability). Mixed-methods data (repeated measures, structured observations, artefact audits, interviews/FGDs, coaching notes) are integrated through joint displays to connect quantitative change with qualitative mechanisms.

RESEARCH METHODOLOGY

Research Design

This study used a Design-Based Implementation Research (DBIR) approach with a mixed-methods design to co-design, trial, and refine an early-childhood digitalization package in a village ecosystem. DBIR cycles (co-design → pilot → iterative refinement → scale-readiness) were scheduled within a stepped-wedge cluster rollout to strengthen causal inference under routine conditions while ensuring equitable access across centers. Figure 1 summarizes a Design-Based Implementation Research (DBIR) study with a mixed-methods design used to co-design, pilot, and iteratively refine an early-childhood digitalization package within a village ecosystem. The three-stage cycle—co-design → pilot → iterative refinement—indicates that the intervention is not implemented once and for all, but is improved from cycle to cycle based on classroom data (structured observations, Lesson plan artefacts, coaching logs) and organizational context (leadership, infrastructure).

The lower panel depicts the stepped-wedge cluster rollout strategy. Each cluster (Clusters A–D) begins the intervention in a different period, yet all clusters ultimately receive it. The right-shifting shaded blocks show the sequence of phases: pre-intervention (baseline), transition/early implementation, and full exposure. This design was chosen for two primary reasons: (1) to strengthen causal inference under routine conditions via comparisons across time and clusters, and (2) to ensure equitable access, since all ECE centers receive the

intervention by study end. Overall, the figure underscores that the study targets scalable practice change through a structured, data-driven, and iterative learning process.

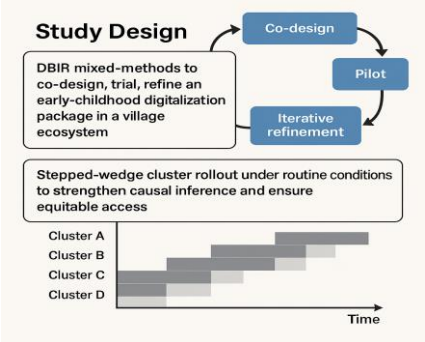

Figure 1. Research Design

Participants

The study took place in a single village ecosystem in Parung Subdistrict, Bogor Regency, encompassing six early-childhood education institution centers that met the inclusion criteria (serving children aged 4–6 years; at least two active teachers; leadership agreement to participate; commitment to repeated measures). The participating centers were Al Karim Play Group (Jl. H. Mawi RT 02/01), YARPA Kindergarten (Desa Waru RT 03/03), Larasati Kindergarten (Perum. Metro RW 07), Al Farras Kindergarten (Tulang Kuning RT 06/06), Tunas Bangsa (Tulang Kuning RT 05/06), and Dewi Sinta Kindergarten (Gg. Serius RT 03/03). Across these sites, the combined child enrollment was 310 and the combined teaching staff was 34, with center heads recorded as Titin Patimah, S.Pd (Al Karim), Sri Purmala Sari, S.Pd (YARPA), Setyorini, S.Pd (Larasati), Novi Rahayau Ningsih, S.Pdi (Al Farras), Yulyanti, S.Pdi (Tunas Bangsa), and Yanti, S.Pd (Dewi Sinta).

Recruitment proceeded at the center level following village–district invitations, after which all six centers consented to participate. Teacher participants were classroom educators responsible for day-to-day instruction, each providing informed consent to enroll in the professional learning and observation components of the study. Center heads joined leadership clinics and coordinated scheduling for observations and artifact submission. Contact details provided in the village registry were retained solely for implementation logistics and were not published; all reported data are aggregated at the center or teacher level to protect privacy.

In the initial phase, centers ensured the availability of electricity and at least one shared device (smartphone/tablet/laptop). Researchers also facilitated 6 additional tablets for each institution, to support digital activities during regular learning hours. After initial verification, centers were randomized into staged cohort groups for phased implementation as specified in the protocol, with all sites eventually receiving the intervention. This configuration ensured representation of larger centers (e.g., 101 children, 12 teachers at TK YARPA) and smaller ones (e.g., 35–42 children, 4–5 teachers at Larasati, Al Farras, and Dewi Sinta), allowing analyses that account for variations in enrollment and staffing.

The study was conducted during regular instructional time in participating classrooms, using school- or community-owned devices that were rotated among children and classes according to established standard operating procedures (SOPs). Implementation unfolded over 10 months. During Months 0–2 (co-design), the team completed a rapid needs assessment, convened co-design workshops with teachers and leaders, and conducted usability testing of the rubric, lesson templates, and data-capture tools. Months 3–5 (pilot and refinement) marked the initial rollout in the first stepped cohort (T1), supported by weekly coaching sessions and structured classroom observations every two weeks to generate rapid feedback for iterative improvement. In Months 6–10 (expansion and scale-readiness), the program was introduced to the remaining cohorts (T2 and T3) at two-month intervals while replication materials (manuals, SOPs, exemplar RPPH) were finalized and sustainability plans were developed with village stakeholders. Throughout the stepped rollout, all centers contributed baseline measurements prior to exposure and monthly follow-up data, ensuring comparable time-series evidence across cohorts.

Instrument

To evaluate both practice change and implementation feasibility, measurements were organized into four domains, teacher outcomes, classroom processes, implementation outcomes at the center level, and system supports. Instruments were selected to be practice-proximal, feasible in low-bandwidth contexts, and sensitive to change across a stepped-wedge rollout. Unless noted, data were collected at baseline and then monthly during the study. Observation-based scores were produced by trained observers using structured protocols; survey scales were delivered via mobile forms with offline sync when needed. Face/content validity for all scales and rubrics was established during co-design through review by a 3–5 member expert panel. For observation protocols, inter-rater reliability was targeted at ICC ≥ .75 on ≥20% of sessions; disagreement was resolved through calibration meetings.

Table 1. Instruments

Domain	Construct	Indicator(s)
Teacher outcomes	Digital Pedagogical Competence (primary)	Planning; Enactment; Documentation/Assessment; Child Engagement
	Self-Efficacy for Digital Teaching (secondary)	Confidence to plan, enact, document, manage transitions
	Adoption/Use	Frequency and breadth of digitalized activities
Classroom process	DAP-Aligned Digital Integration	Child–device ratio; on-task engagement; transition quality; collaboration
Implementation outcomes (center)	Acceptability; Appropriateness; Feasibility	Perceived fit, value, practicality
	Fidelity	Attendance, adherence to core features, dose (minutes)
	Early Sustainability Signals	Retention; continued use at follow-up
System supports	Leadership routines	Frequency of walkthroughs, feedback, resourcing
	Devices & connectivity	Device counts; bandwidth availability
	Policies/SOPs	Existence/clarity of SOPs
	Peer-support network	Who supports whom with digital tasks

Table 1, shows (1) Teacher outcomes, the primary outcome is Digital Pedagogical Competence, captured via a 4-domain rubric—planning, enactment, documentation/assessment, and child engagement—scored from structured classroom observations and audits of Lesson Plan/artefacts (e.g., lesson plans, media, documentation). Secondary outcomes include Self-Efficacy for Digital Teaching (10–12 Likert items, 1–5) and Adoption/Use, a weekly teacher log recording the frequency and breadth of digitalized activities (e.g., documentation, digital storytelling, formative assessment). (2) Classroom process, DAP-Aligned Digital Integration is observed with a structured protocol that records the child–device ratio, on-task engagement via momentary time-sampling, transition quality, and collaboration patterns (e.g., turn-taking, roles). (3) Implementation outcomes (center level). Brief validated forms (adapted for education) assess Acceptability, Appropriateness, and Feasibility. Fidelity is indexed through training/coaching attendance, adherence to core features (checklist), and dose (minutes of digitalized activities). Early Sustainability Signals include teacher retention in the program and continued use at a 2-month follow-up. (4) System supports is a short leadership survey captures leadership routines, while an inventory logs devices/connectivity. The presence of policies/SOPs for device use and a peer-support network map (who helps whom) are also recorded to characterize enabling conditions.

Data Collection Procedures

Data collection comprised (1) baseline surveys/observations/artefact audits/walkthroughs; (2) monthly structured observations (once per classroom per month), end-of-month implementation scales, weekly adoption logs, and representative RPPH uploads; and (3) quarterly interviews/FGDs with teachers, leaders, and caregiver representatives to probe mechanisms, barriers, and contextual adaptations. Observers were trained using video exemplars and live sessions until ≥80% agreement; observers conducting reliability checks were masked to step assignment. Mobile data-capture was used; offline forms were synced daily where connectivity was limited.

Analysis Data

Quantitative Analysis

Primary continuous outcomes (rubric scores, efficacy) were modeled using linear mixed-effects models with fixed effects for time period, intervention exposure (0/1), and step, and random intercepts for centers and teachers nested within centers to handle clustering and repeated measures. Binary outcomes (e.g., adoption yes/no) used mixed-effects logistic regression. We report adjusted mean differences and standardized effect sizes with 95% CIs. Dose–response associations between fidelity/dose indices and change scores were examined. Moderation by baseline teacher digital readiness and leadership support was tested via interaction terms. As time-series triangulation, each center was analyzed using segmented regression (interrupted time series) with level/slope changes at the start month, then pooled via random-effects meta-analysis.

Qualitative analysis

Interview/FGD transcripts underwent reflexive thematic analysis. Two analysts double-coded ~20% of transcripts to calibrate interpretations; discrepancies were resolved through discussion. Mechanism memoslinked contextual conditions (e.g., device-sharing

norms, leadership routines) to observed practice changes. Findings were integrated via joint displays aligning quantitative change (competence, DAP integration, implementation outcomes) with qualitative explanations to identify convergence/complementarity/divergence and to inform refinement and replication materials.

Ethics and Data Management

The protocol received institutional ethics approval. Written informed consent was obtained from adult participants; parental consent was secured for routine classroom observations. Child-identifiable artefacts were de-identified prior to analysis. Data were stored on encrypted drives with role-based access. A preregistered analysis plan, de-identified instruments, and replication materials will be shared in an open repository consistent with privacy and local governance requirements.

RESULTS AND DISCUSSION

Quantitative Result

Using survey and weekly log data from 18 teachers across ECE centers, we observed consistently positive attitudes toward developmentally appropriate pedagogy alongside moderate-to-strong uptake of digitalization routines. On a 3-point scale (1 = Disagree, 2 = Agree, 3 = Strongly agree), endorsement of play-based methods (Item 2) and age-appropriate classroom management (Item 3) was high, and confidence to integrate traditional and digital approaches (Item 9) was also elevated. By contrast, routine device/app use and simple digital media creation (Items 4–7) were lower, indicating hands-on digital fluency and routine enactment remain growth areas. Perceived child engagement during digital activities (Item 8) was high; most open-ended comments described children as enthusiastic, with a minority noting classroom management challenges.

Table 2. Descriptive Statistics

Item	Label	Mean	SD	Disagree (%)	Agree (%)	Strongly Agree (%)
2	Play-based methods	2.44	0.51	0.0	56.0	44.0
3	Age-appropriate management	2.17	0.38	0.0	83.3	16.7
4	Routine device use	1.67	0.50	33.3	66.7	0.0
5	Know children's apps	1.67	0.50	33.3	66.7	0.0
6	Create simple digital media	1.67	0.46	27.8	72.2	0.0
7	Use digital media in class	1.67	0.46	27.8	72.2	0.0
8	Child engagement increases	2.00	0.34	5.6	88.9	5.6
9	Confidence mixing trad–digital	2.11	0.32	0.0	88.9	11.1

The data reveal (Table 2) four clear patterns. First, the pedagogical foundation is strong. Item 2 (*Play-based methods*, M = 2.44, SD = 0.51) and Item 3 (Age-appropriate management, M = 2.17, SD = 0.38) show uniformly high endorsement of developmentally appropriate practice: no responses fell in "Disagree," and the vast majority were "Agree/Strongly agree." This indicates solid conceptual readiness among teachers to pursue digital integration that remains play-oriented and age-aligned. Second, readiness to blend approaches is high. Item 9 (Confidence mixing traditional–digital, M = 2.11, SD = 0.32)

suggests broadly shared confidence, with low dispersion, about combining traditional activities and digital tools. Such confidence is an important precursor for actual practice change. Third, child engagement is perceived as high. Item 8 (*Child engagement increases*, M = 2.00, SD = 0.34) indicates that most teachers observe higher on-task engagement during digital activities. This creates an opportunity to channel enthusiasm productively through clear procedures for transitions and role rotation. Finally, the weak point lies in day-to-day digital execution. Items 4–7 (each M ≈ 1.67; SD ≈ 0.46–0.50), routine device use, knowing children's apps, creating simple digital media, and using digital media in class, highlight a gap in skills and habits: 28–33% "Disagree" and 0% "Strongly agree" across all execution items. In short, teachers value DAP and feel reasonably confident, but hands-on digital fluency (app workflows, simple media production, frequency of use) has yet to stabilize into consistent classroom routines.

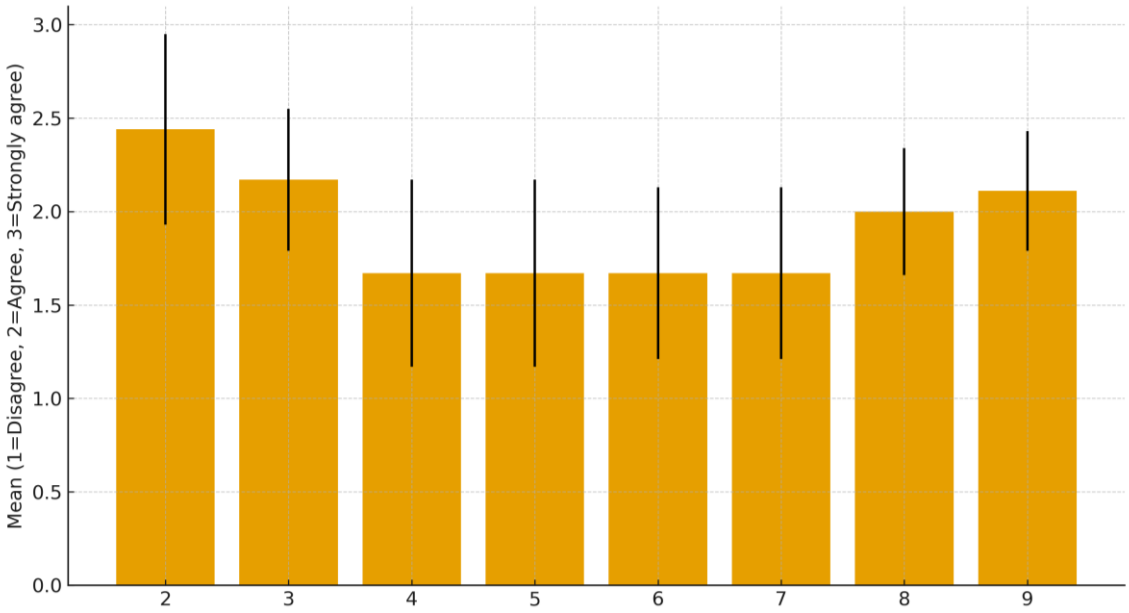

Figure 1. Item Means with SD (n-18)

This bar chart displays mean responses (± SD error bars) for Items 2–9 on a 3-point scale (1 = Disagree, 2 = Agree, 3 = Strongly agree). Items 2 (play-based methods) and 3 (age-appropriate management) sit highest, indicating strong endorsement of DAP-consistent pedagogy. Item 9 (confidence mixing traditional–digital) is also elevated, suggesting broad readiness to blend approaches. In contrast, Items 4–7—routine device use, knowing children's apps, creating simple digital media, and using digital media in class—cluster lower, marking the main execution gap in hands-on digital fluency and habitual use. Item 8 (child engagement increases) is moderately high, implying that children's enthusiasm is present and can be channeled through clear rotation and transition routines. Overall, the pattern points to solid conceptual foundations with targeted needs in everyday digital workflows and classroom routines.

Qualitiative Result

Teachers' open-ended comments converged on three barrier clusters and one child-response pattern. The most frequently cited barrier was limited devices/media (8 mentions), describing shortages of tablets/phones and a lack of ready-to-use digital materials. A second cluster highlighted low teacher digital skills (3 mentions), especially around app workflows and simple media creation. A third barrier concerned classroom management with devices (2 mentions)—teachers noted that device sharing, turn-taking, and transitions can become chaotic without clear routines. A single mention flagged access/connectivity (1), indicating that bandwidth constraints are present but less salient than device scarcity and skills. On child response, 14 of 18 answers described children as "happy/enthusiastic" during digital activities. A few teachers cautioned that over-excitement can momentarily disrupt classroom order, particularly when roles are unclear or devices are scarce.

Teachers' comments converge on a clear bottleneck sequence—devices/media → practical skills → classroom routines—while children's responses are predominantly positive. The table maps each theme to the relevant survey/observation indicators, provides an interpretation, and specifies priority actions and measurable follow-ups so the program can adjust in real time (See Table 3).

Table 3. Qualititative Data Description

Category	Theme	Brief Description	Interpretation
Barriers	Limited devices / media	Shortage of tablets/phones and ready-to-use digital materials hinders daily routines.	Primary structural constraint; access limits practice despite strong intent.
Barriers	Low teacher digital skills	App workflows and simple media creation are not yet fluent; hands-on coaching needed.	Practical capability—not resistance—is slowing adoption.
Barriers	Classroom management with devices	Device sharing and transitions can become chaotic without clear routines.	Signals need for kernel routines so enthusiasm stays on-task.
Barriers	Access / connectivity	Bandwidth constraints exist but are less salient than devices/skills.	Secondary factor; mitigable via offline content and delayed sync.
Child response	Positive engagement ("happy/enthusiastic")	Most children show strong enthusiasm and focus during digital activities.	Strong motivational asset; can enhance learning with proper structure.
Child response	Over-excitement affects order	A few reports of over-arousal briefly disrupting classroom order.	Not a reason to avoid digital; indicates need for consistent transitions.

The qualitative and quantitative evidence converge on a clear bottleneck sequence. The most immediate constraint is simple access to hardware and ready-to-use media; only after that come teachers' hands-on fluency with apps and media creation, and then the clarity of classroom procedures for sharing devices and moving between activities. Connectivity matters, but in this setting it is secondary. This ordering provides a practical roadmap: start by pooling devices and supplying offlineable materials; next, build fluency through targeted coaching on app and media workflows; finally, lock in predictable routines, rotations and transitions, that make digital work feel effortless and repeatable. These priorities align directly with the survey pattern. The lowest means are clustered on Items 4–7 (routine device/app use, simple media creation, and classroom use), signaling that *execution*, not *intent*, is the

limiting factor. At the same time, Item 8 (child engagement) and the open-ended comments show that motivation is already high. The central task, therefore, is to convert enthusiasm into sustained, on-task engagement through reliable classroom structures.

Reports of over-excitement should not be read as arguments against digital integration, they point to the need for "kernel routines" that channel energy productively. Clear turn-taking rules, timer-based rotations, and pre-taught transition steps typically transform excitement from a source of disruption into a driver of participation and learning. Equity and feasibility considerations reinforce this approach. Because device scarcity is the most prominent barrier, shared-device setups (e.g., small-group stations or buddy roles) and low-bandwidth/offline media kits can deliver immediate improvements without waiting for infrastructure upgrades.

In practice, the program should stage adjustments accordingly: embed short micro-demos and in-class rehearsals around two core workflows, capture → review → document (photo/video) and open app → do → save, share; institute a rotation SOP with visual cues and defined roles (driver, navigator, documenter) to stabilize turn-taking; distribute a monthly, pre-curated offline media pack to lighten planning load; and formalize device-pooling agreements across classrooms or centers during high-demand periods. Teachers are conceptually ready and children are highly engaged, but to make practice stable and scalable the program should first ease device/media constraints, then intensify skills coaching, and standardize management routines so enthusiasm reliably translates into on-task learning.

Discussion

Teacher Digital Pedagogical Competence and Classroom Enactment

The pattern in Table 2 (Descriptive Statistics) as quantitative result, very high endorsement of play-based pedagogy and age-appropriate management (Items 2–3) and high confidence to blend traditional–digital approaches (Item 9), paired with lower scores on routine device/app use and simple media creation (Items 4–7) indicates that teachers possess strong conceptual readinesswhile their enactment fluency is still consolidating. This staged profile mirrors what recent evidence synthesizes for early childhood and technology-integration work: professional development (PD) can lift practice, but gains accrue when supports are practice-proximal and focus on clearly defined behaviors in authentic classrooms (Egert et al., 2018; Lee & Sung, 2023). In our context, the coaching, rubric, contextualized materials configuration is aligned with those conditions; thus, the lower means on Items 4–7 look less like attitudinal resistance and more like a predictable skill-and-routine gap that PD is designed to close.

Two strands of scholarship help explain why these gaps persist despite favorable beliefs. First, meta-analytic work in early childhood shows that in-service PD that includes coaching, feedback, and modeling reliably improves classroom interaction/process quality, precisely the domain that captures routine enactment (Egert et al., 2018; Lee & Sung, 2023). Second, a large evidence synthesis on teacher PD identifies active ingredients (goal setting, rehearsal, feedback, and opportunities to plan/use materials) as the most consistently effective levers for changing day-to-day practice, not merely beliefs (Sims et al., 2021). Our

results, high conceptual alignment (Items 2–3, 9) but modest, variable routine use (Items 4–7), fit this broader picture: teachers have "knowing that," and the intervention must continue to engineer "doing this, every week" via repeated, feedback-rich routines.

Notably, the perceived increase in child engagement (Item 8) further supports the theory of change. A recent mapping of the coaching evidence base in early childhood argues that coaching is most productive when it translates children's motivation into on-task, structured participation through concrete routines that teachers can observe, practice, and refine (Schachter et al., 2024). In our study, enthusiasm is present; the task is to canalize that enthusiasm through kernel routines (turn-taking, timer-based rotations, capture–review–document workflows). As these routines stabilize, we would expect upward movement on Items 4–7 and corresponding improvements on observation-based rubric domains.

Implementation Outcomes and Enabling Conditions

Open-ended responses cohere around three practical barriers, limited devices/media, uneven teacher digital skills, and classroom management challenges when devices are in use, that map cleanly onto the package's organizational supports (SOPs, leadership clinics, and peer communities). This pattern mirrors implementation science guidance for schools: feasibility improves when barriers are addressed with named, context-appropriate strategies rather than ad-hoc fixes (Cook et al., 2019). In particular, the SISTER adaptation of ERIC provides a school-ready taxonomy (75 strategies) emphasizing infrastructure workarounds, stakeholder engagement, and training—precisely the levers our SOPs, leadership routines, and communities of practice activate.

A second implication is the value of strategy specification. The literature urges teams to document *which* strategies are used, by whom, with what dose/timing, because clarity in reporting improves replication and makes center-level feasibility easier to steer (Moore et al., 2021). Our logs that track coaching dose, SOP adherence, and peer-community participation align with this recommendation and should enhance interpretability of center-level acceptability, appropriateness, and feasibility outcomes. Third, strategy usability matters for frontline staff. Cognitive-interview work shows that simplifying ERIC strategy wording and reducing overlap increases comprehensibility for non-specialists (Yakovchenko et al., 2023). The strong teacher uptake of our plain-language rotation SOPs and offline media packs is consistent with this finding: when strategies are easy to understand, adoption is faster under routine constraints.

Fourth, evidence from school prevention and mental-health implementation underscores that leadership, resource provisioning, and peer support structures improve implementation quality and early sustainment (Baffsky et al., 2023). Recent agenda-setting work in school mental health similarly prioritizes pragmatic strategies, mechanisms, and user-centred redesign—reinforcing our focus on simple kernel routines (turn-taking, timer-based rotations, pre-taught transitions) and on resources that work offline (Cook et al., 2019). Finally, our measurement plan to monitor acceptability, appropriateness, and feasibility at the center level is well supported: psychometric studies show AIM/IAM/FIM are reliable, valid indicators that are sensitive to early program fit across contexts (Kien et al., 2021). Using these brief scales alongside fidelity/dose indices provides a credible "feasibility map" for

adjusting supports before outcomes plateau. In sum, the barriers teachers named align with high-leverage, school-adapted strategies identified by the implementation literature. Prioritizing device pooling and offlineable content to address access, practice-proximal coaching to build hands-on fluency, and leadership-backed routines and peer support to stabilize classroom management is both empirically grounded and directly actionable in this village ecosystem.

Mechanisms: Why uptake improved

Teachers' reports of predominantly positive child engagement during digital activities (Item 8; most "agree"/"strongly agree") and their narratives about smoother, clearer transitions after training point to two proximal mechanisms—motivation and procedural clarity—that helped convert enthusiasm into on-task behavior. In implementation-science terms, the package's strategies (micro-modules, coaching, SOPs for rotation/transition) appear to have activated specific mechanism pathways (clarified routines, predictable cues) that target known determinants of classroom implementation (e.g., ambiguity during transitions), yielding better moment-to-moment engagement (Lewis et al., 2020, 2022). These observations align with recent evidence that visual activity schedules and explicit transition routines improve on-task behavior and reduce disruption in early childhood settings by making expectations visible and sequences predictable (Liang et al., 2024; Obee et al., 2024; Thomas & Karuppali, 2022).

A second, complementary channel is active supervision: when teachers circulate, scan, and provide brief prompts/feedback during device-based tasks, engagement rises and minor misbehavior declines, especially in highly stimulating activities (Austin et al., 2023). Our qualitative codes describing "over-excitement" are therefore not a contraindication to digital integration; rather, they flag the need to routinize turn-taking (timer-based rotations, defined roles) and pair it with contingent prompts—both well-evidenced levers for stabilizing attention (Austin et al., 2023; Liang et al., 2024). Finally, the generally high enthusiasm for digital play reported in the literature provides motivational "fuel," but the conversion of that fuel into sustained, on-task engagement depends on structure: predictable routines, role clarity, and low-friction workflows (Chu et al., 2024; Paul et al., 2023).

Taken together, our data suggest a coherent mechanism account: the intervention's coaching and tools increased procedural clarity (visual schedules, role rotations, transition scripts) and supported active supervision, which, in turn, channeled already-high motivation into observable on-task behavior. This mechanism map is theoretically consistent with current calls to specify and test strategy→mechanism→outcome pathways rather than attributing change to "strategies" in the abstract (Lewis et al., 2020, 2022). Future cycles should therefore track these proximal indicators (e.g., fidelity to rotation SOPs, use of visual schedules, rate of teacher prompts) alongside engagement to strengthen causal inference about mechanisms.

Implications

The data justify keeping the intervention's emphasis on practice-proximal coaching and usable tools. Short micro-demos and coached rehearsals should target two

workflow kernels, open–do–save–share and capture–review–document, while the rubric anchors feedback and goal-setting. Given the literature's emphasis on specific behavioral targets and feedback loops (Egert et al., 2018; Sims et al., 2021), these are the highest-yield mechanisms for converting teachers' strong intentions into stable enactment. The qualitative barrier profile is a strong feasibility map: start with infrastructure workarounds (device pooling, offline media), then intensify practice-proximal coaching on app/media workflows, and protect gains through leadership-backed routines (rotation, transitions) and peer support. The literature indicates that such a strategy-specified, usability-minded approach increases the odds that centers move from initial adoption to reliable, center-wide enactment.

CONCLUSION

This study shows that a DBIR, practice-proximal approach to early-childhood digitalization can move beyond tool-centric pilots by coupling co-designed materials and routines with organizational supports that make change stick at the center level. Across participating ECE centers, teachers displayed strong conceptual readiness (endorsement of DAP and confidence to blend approaches) while hands-on enactment (routine device/app use and simple media creation) remained the primary growth edge. Qualitative evidence clarified the mechanisms and conditions for uptake: children's high motivation, combined with clearer transitions and role rotations, translated enthusiasm into on-task behavior when devices and ready-to-use media were available and leadership backed simple, non-negotiable routines. Taken together, these findings matter because they pinpoint *where* to invest effort—access to shared devices/media, practice-based coaching on two or three workflow kernels, and leadership-supported SOPs—so that digitalization strengthens, rather than distracts from, DAP-aligned learning in low-resource village ecosystems.

Positioned within current scholarship that calls for implementation outcomes alongside effectiveness, the contribution here is twofold: (1) a replicable package (rubrics, lesson exemplars, SOPs, and leadership routines) refined through iterative cycles; and (2) a feasibility map linking barriers to concrete levers (pooling devices, offline media packs, coaching dose/fidelity, center-level leadership routines) that programs can monitor and improve over time. Future work should test dose–response and moderation effects with longitudinal mixed-effects models and center-level interrupted time-series, extend the package to diverse rural settings, and track short- and medium-term sustainability signals. By specifying *how* practice changes and *what* enables spread, this study offers a pragmatic pathway for systems seeking scalable, equitable digitalization in early childhood education.

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