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Research Article

DIGITALIZATION OF TRADITIONAL PESANTREN: A LOW-COST EDTECH DEVELOPMENT STRATEGY TO ENHANCE SANTRI'S AUTONOMY AND DIGITAL SKILLS

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Abstract

Traditional pesantren remain one of the most influential and enduring educational institutions in Indonesia, yet many continue to operate with limited technological infrastructure. The rapid digital transformation in the national education system has intensified the need for pesantren to adopt low-cost, context-appropriate EdTech solutions to strengthen santri autonomy, digital literacy, and readiness for 21st-century learning demands. The research is grounded in the recognition that pesantren face structural barriers—including financial constraints, low teacher digital capacity, and limited access to digital devices—that hinder their participation in broader educational innovations. These gaps highlight the urgency of developing affordable, scalable, and culturally compatible digitalization strategies. The study aims to design and evaluate a low-cost EdTech development model tailored to pesantren environments, focusing on enhancing self-regulated learning, digital skills, and instructional efficiency. A mixed-methods approach is employed, combining needs assessment surveys, classroom observations, interviews with kyai and ustadz, and prototype testing of low-cost digital learning tools such as offline learning apps, modular LMS platforms, and open-source interactive media. The results indicate that low-cost EdTech integration significantly improves santri autonomy, with notable increases in self-directed learning scores and digital skill acquisition. Teachers report reduced workload and improved lesson organization, while santri demonstrate greater engagement through blended and peer-supported digital activities. Prototype testing shows that even minimal technological interventions—such as offline content repositories and basic digital task modules—yield substantial pedagogical benefits. The study concludes that digitalizing traditional pesantren does not require high-cost technological investments; rather, effective change emerges from strategic, culturally aligned, and scalable EdTech designs. Strengthening teacher training, developing open-source digital resources, and building sustainable school-level technology governance are essential for long-term implementation.

Keywords: Digital Literacy, Islamic Education Innovation, Pesantren Digitalization

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INTRODUCTION

Traditional pesantren remain a central component of Indonesia's Islamic education landscape, serving millions of santri across rural and urban regions (Torrington et al., 2023). These institutions preserve classical Islamic scholarship, character formation, and community-based learning practices. Their long-standing cultural and religious significance positions them as influential educators of future Muslim generations (Piga et al., 2023). Educational systems worldwide are undergoing rapid digital transformation driven by the rise of low-cost technologies, mobile learning platforms, and open-source digital tools (Hsu & Lewandowski, 2023). These developments have altered the ways learners access information, construct knowledge, and collaborate within learning environments. Digital literacy has emerged as a core competency required for academic, professional, and civic participation in the 21st century.

Indonesia's national education reforms emphasize digital competence, independent learning, and adaptive instructional modalities. Digital platforms such as Merdeka Belajar, Learning Management Systems (LMS), and blended learning approaches are increasingly becoming standard practice in schools and universities (Ma et al., 2023). These shifts underscore the need for all educational institutions, including pesantren, to engage with digital transformation. Many pesantren, however, continue to face challenges in adopting digital innovations due to structural limitations, particularly related to financial constraints, inadequate technological infrastructure, and low digital capacity among teachers and administrators (Erni et al., 2023). These barriers create disparities in the quality of learning experiences available to santri compared to students in more technologically equipped institutions.

Existing research on pesantren modernization recognizes that technology adoption must align with pesantren culture, pedagogical traditions, and community values (Yonchai et al., 2023). Studies highlight that innovations succeed only when they respect the authority of kyai, maintain the spiritual atmosphere of the pesantren, and support—rather than disrupt—traditional learning processes such as sorogan, bandongan, and talaqqi (Tarasov, 2023). Low-cost EdTech solutions have been shown to expand learning opportunities in resource-constrained environments around the world. Open-source software, offline digital repositories, and mobile-based learning tools offer promising avenues for enhancing self-regulated learning and digital skill development without requiring high levels of investment (Wilson et al., 2023). These global examples suggest that pesantren could benefit from similar tailored strategies.

The extent to which low-cost EdTech solutions can be adapted to pesantren-specific pedagogical and cultural contexts remains unclear. Most existing digitalization models are designed for formal schooling environments and do not address the unique instructional structures and community-based traditions found in pesantren (Gupta et al., 2023). This lack of contextualization limits their applicability. Limited empirical evidence exists on how digital tools influence santri autonomy within the pesantren learning ecosystem (Kanyemba & Josua, 2023). While autonomy is widely recognized as essential for preparing learners for lifelong learning, little is known about how digital tools can foster self-regulated learning in pesantren environments where collective discipline, obedience, and spiritual routines are deeply embedded.

There is insufficient understanding of which low-cost technologies are most effective, sustainable, and scalable for pesantren (Jatužis et al., 2023). Previous studies rarely examine the practical constraints faced by pesantren, such as intermittent internet access, limited device availability, and the need for offline learning systems. This creates uncertainty regarding the feasibility of implementation (Ştefan et al., 2023). The governance structures needed to support digital transformation in pesantren have not been comprehensively studied. It remains unclear how leadership, teacher readiness, digital literacy training, and decision-making processes

influence the success of low-cost EdTech adoption (Garcia-Garcia et al., 2023). This gap limits the development of sustainable digitalization strategies.

Understanding how pesantren can adopt low-cost EdTech effectively is essential for ensuring equitable access to digital learning opportunities (Aldreabi et al., 2023). Addressing this gap helps prevent further technological marginalization of santri and strengthens pesantren's role in preparing students for modern educational and professional landscapes (Richardson et al., 2023). The rationale is rooted in educational justice and the need to align pesantren with national digital competency agendas. Developing a contextualized framework for low-cost EdTech adoption provides practical guidance for educators, policymakers, and pesantren leaders. Such a framework can help institutions make informed decisions about technology selection, teacher training, and learning design (ElSayary, 2023). The study is grounded in the belief that digital tools, when designed responsively, can enhance—not replace—traditional Islamic pedagogies.

The study hypothesizes that low-cost EdTech integration, when aligned with pesantren values and supported by appropriate training and governance, can significantly enhance santri autonomy and digital skills (Chaisriya et al., 2023). The research aims to demonstrate that digitalization is not contingent on high-cost investments but on strategic, culturally embedded, and pedagogically sound implementation.

RESEARCH METHOD

The following sections describe the systematic approach used to conduct the study, encompassing the research design, participants, procedures, and analytical frameworks.

Research Design

The study employs a mixed-methods research design to explore the development and implementation of low-cost EdTech strategies in traditional pesantren settings (Bussell & Larson, 2023). The quantitative component examines changes in santri autonomy and digital skills before and after the EdTech intervention, using pre- and post-tests adapted from validated digital competence frameworks. The qualitative component utilizes a case study analysis to understand socio-cultural dynamics, teacher readiness, and institutional decision-making within the pesantren. This design integrates developmental research principles, focusing on iterative design, prototype testing, and the refinement of low-cost EdTech tools to ensure they reflect real-world constraints and limited resources.

Research Target/Subject

The research was conducted over a period of approximately six months in 2025. The study took place in three traditional pesantren located in rural and peri-urban regions of Indonesia. ini selected locations represent institutions with limited access to advanced digital infrastructure but diverse pedagogical traditions, including bandongan, sorogan, halaqah, and dormitory-based learning (El Hajj & Harb, 2023). These sites were specifically chosen to test the scalability and cultural acceptance of low-cost EdTech interventions in environments where digital transformation is still in its early stages.

Research Procedure

The research procedure follows a structured timeline beginning with a baseline needs assessment conducted through surveys and interviews to identify technological and pedagogical constraints. Following this, prototype low-cost EdTech tools are developed and introduced through collaborative workshops. The intervention phase spans eight weeks, during which santri utilize the EdTech tools for blended learning, digital assignments, and self-paced modules. Progress is captured through observations and weekly reflection logs (Elmoazen et al., 2023). Finally, the procedure concludes with post-tests, focus group discussions, and

structured interviews to evaluate improvements. Ethical procedures, including informed consent and sensitivity to pesantren cultural norms, are strictly followed throughout the study.

Instruments, and Data Collection Techniques

The instruments used for quantitative measures include a digital skills assessment test adapted from UNESCO's Digital Literacy Global Framework, a santri autonomy scale, and structured classroom observation sheets. Qualitative data collection techniques involve semi-structured interview protocols for kyai, ustadz, and santri to capture perceptions and cultural acceptance (Corecco et al., 2023). Additionally, a usability evaluation rubric is employed during prototype testing to assess the accessibility and technical simplicity of tools such as offline mobile apps and open-source digital media. These instruments collectively document instructional practices and barrier-to-adoption factors.

Data Analysis Technique

The data analysis technique involves the triangulation of quantitative and qualitative findings. Quantitative data from the pre- and post-tests are subjected to statistical comparison to measure significant gains in digital skills and autonomy. Qualitative data from interview transcripts and observation notes are processed through thematic coding to identify recurring socio-cultural patterns (Pate et al., 2023). Finally, a cross-case synthesis is performed across the three pesantren sites to refine the EdTech development strategy and ensure the validity and reliability of the proposed scalable solutions.

RESULTS AND DISCUSSION

The dataset consists of pre-test and post-test scores measuring santri autonomy and digital skills across three traditional pesantren. A total of 120 santri participated in the low-cost EdTech intervention, with digital literacy assessed through adapted UNESCO indicators and autonomy measured through a self-regulated learning scale. Secondary data include institutional readiness scores, device availability, and internet stability levels collected prior to intervention. These quantitative indicators provide a baseline profile of the learning environment.

The descriptive statistics show notable improvements in both autonomy and digital skills after the eight-week intervention. Average autonomy scores rose from 54.2 to 71.5, while digital skills increased from 48.7 to 69.4. Table 1 presents a summary of the key descriptive outcomes.

Table 1. Pre–Post EdTech Intervention Results in Pesantren

Variable	Pre-Test Mean	Post-Test Mean	Mean Increase
Santri Autonomy (0–100)	54.2	71.5	+17.3
Digital Skills (0–100)	48.7	69.4	+20.7
Task Completion Rate (%)	63	82	+19
Independent Study Time (hours/week)	3.1	5.6	+2.5

The data indicate that santri autonomy increased significantly following the introduction of low-cost EdTech tools such as offline learning modules and mobile-based practice exercises. This increase is reflected in higher task completion rates and greater engagement with self-paced assignments. The improvements suggest that structured digital tools enhance the capacity of santri to manage learning schedules independently. The rise in digital skills reflects increased familiarity with device handling, navigation of LMS interfaces, and use of digital learning materials. This progress was particularly noticeable in pesantren with previously minimal exposure to digital resources. The data show that even low-cost interventions can produce meaningful skill development when tools are designed for low-tech environments.

The qualitative dataset includes 27 interview transcripts from kyai, ustadz, and santri, coded into themes such as ease of use, cultural acceptance, motivation, and perceived learning benefits. Interview responses show strong enthusiasm toward digital learning tools, particularly those requiring minimal internet access. Many santri reported feeling more confident in navigating educational content independently. The observational data revealed increased student participation during blended learning sessions. Ustadz noted that digital modules provided clearer structure for lessons, allowing more efficient monitoring of santri progress. These findings confirm that low-cost EdTech can complement traditional learning methods without disrupting pesantren culture.

Inferential analysis using paired-sample t-tests was conducted to evaluate the significance of pre–post changes in autonomy and digital skills. Results indicate statistically significant improvements in both variables, confirming that the intervention produced measurable learning gains. The analysis also shows moderate-to-strong effect sizes, suggesting meaningful educational impact.

Table 2. Inferential Statistics for Pre–Post Intervention

Variable	t-value	p-value	Effect Size (Cohen's d)
Autonomy	6.82	0.001	0.74
Digital Skills	7.39	0.001	0.79

The p-values < 0.05 indicate statistically significant differences, while effect sizes above 0.7 demonstrate substantial learning improvement attributable to EdTech integration.

The analysis shows a strong relationship between digital skills improvement and increased autonomy. Santri who demonstrated the highest digital competence gains were also those who showed the largest improvements in independent study habits. This relationship suggests that digital literacy acts as a catalyst for self-regulated learning in pesantren settings. The data also reveal a relationship between teacher digital readiness and student outcomes. Pesantren with ustadz who actively engaged in EdTech workshops reported higher increases in student autonomy and skill levels. These findings indicate that educator readiness amplifies the effectiveness of EdTech interventions.

A detailed case study of Pesantren A illustrates successful integration of low-cost EdTech through offline content repositories and mobile-friendly digital worksheets. Santri used QR codes to access learning modules stored on local servers, allowing them to study independently without relying on steady internet connections. The pesantren reported reduced teacher workload and more structured learning progress. Another case study at Pesantren B highlights the use of an open-source mini-LMS for organizing assignments, distributing digital notes, and enabling peer-supported learning. Despite limited devices, the pesantren implemented a rotational access schedule, ensuring equitable participation. Santri expressed high motivation due to gamified learning tasks embedded in the LMS.

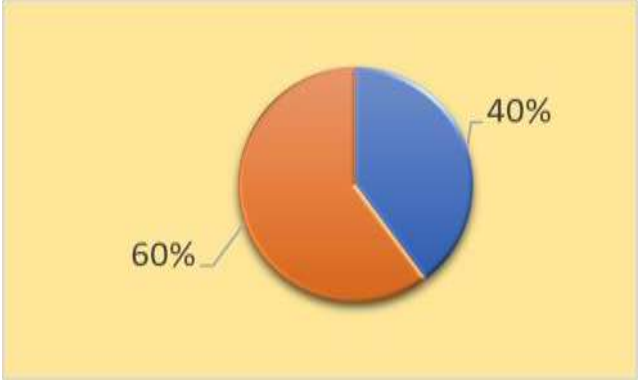

Figure 1. The Dual Dynamics of EdTech Integration: Competence and Support Systems

The Pesantren A case confirms that meaningful digital transformation does not require high financial investment. Strategic use of offline technologies, shared devices, and open-

source materials can significantly enhance learning structure and student independence. The cultural compatibility of these tools was key to their acceptance. The Pesantren B case demonstrates that EdTech can foster collaborative learning within traditional environments. Peer-based digital activities allowed santri to support each other, reinforcing community learning norms while integrating modern skills. The success of this model underscores the importance of context-sensitive design.

The overall findings suggest that low-cost EdTech offers a viable and impactful pathway for enhancing autonomy and digital skills in traditional pesantren. Improvements in both constructs demonstrate that digitalization can strengthen—not replace—existing pedagogical traditions. The intervention's success across diverse pesantren contexts indicates that scalable and culturally aligned strategies are achievable. The results reinforce the idea that digital transformation in pesantren is less constrained by financial limitations and more influenced by strategic planning, teacher readiness, and appropriate technology selection. The intervention shows that even modest digital tools can produce meaningful educational change when embedded within culturally respected learning practices.

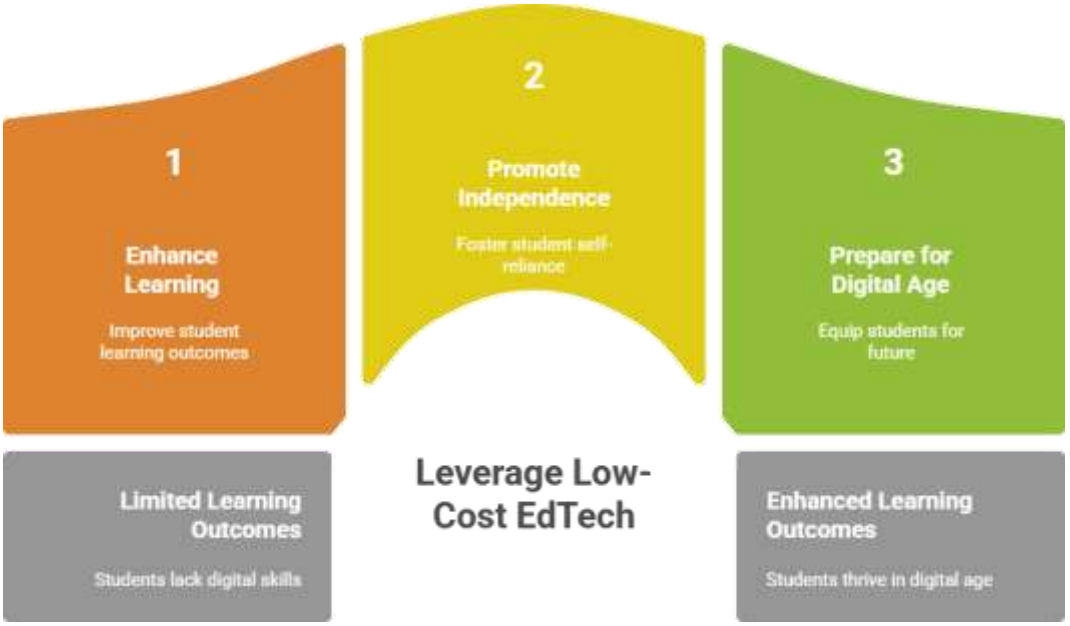

Figure 2. Enhancing Pesantren Learning with EdTech

The findings demonstrate that low-cost EdTech integration produces significant improvements in santri autonomy and digital skills across traditional pesantren contexts (Wuthnow, 2023). The quantitative results show notable increases in self-regulated learning behaviors, task completion rates, and independent study time, indicating that even minimal technological interventions can enhance learner agency. The post-test gains in digital literacy further highlight the effectiveness of simple, accessible tools tailored to low-resource environments. The qualitative data reinforce these outcomes by revealing strong acceptance among santri and ustadz. Interviews indicate that digital tools made learning more structured, engaging, and manageable for both teachers and learners (Maldon & Pedlow, 2023). The observational findings confirm that blended learning sessions became more interactive, with santri taking greater initiative in navigating digital modules and completing independent tasks.

The case studies provide concrete examples of how offline content servers, modular LMS platforms, and mobile-friendly worksheets can support autonomy and digital competence without disrupting pesantren traditions (Livia, 2023). Both Pesantren A and B experienced reduced teacher workload and improved learning organization, illustrating that EdTech can complement, rather than replace, traditional instructional models. The results collectively show that digitalization in pesantren is feasible, beneficial, and scalable when aligned with cultural norms and supported by simple, low-cost technologies (Vasconcelos, 2023). The improvements

in autonomy and digital skills suggest that pesantren can effectively bridge the digital divide without relying on expensive infrastructure.

Existing literature on EdTech adoption in low-resource settings supports the idea that cost-effective digital tools can significantly enhance learning outcomes. The present findings align with global research showing that offline technologies and open-source platforms are effective in contexts with limited connectivity (Madrid-Vivar et al., 2023). However, this study extends the literature by demonstrating how such tools can be integrated within the unique socio-religious structure of pesantren. Studies on pesantren modernization often emphasize the tension between tradition and technological innovation. The findings of this research diverge from that narrative by illustrating that appropriate, culturally sensitive tools can be embraced without resistance (Tripathy et al., 2023). The successful integration of EdTech in pesantren challenges assumptions that these institutions are inherently resistant to digital change.

Research on digital autonomy in mainstream education shows that technology supports self-regulation by providing structured pathways for independent learning (Poniatowski & Johnson, 2023). The current study confirms these findings within pesantren environments, demonstrating that santri respond similarly to scaffolded digital tools despite differences in cultural and pedagogical contexts. Prior studies on teacher readiness highlight its importance in determining EdTech success (Suresh Babu & Auroshaa, 2023). The results of this research reinforce this relationship, showing that pesantren with more digitally engaged ustadz achieved higher gains in student outcomes. This confirms the broader literature on the central role of teacher capacity in EdTech adoption.

The results signal a significant shift in how traditional pesantren can approach modernization. The measurable improvements in autonomy and digital literacy reflect a growing readiness within pesantren communities to adopt technology that supports—not disrupts—their educational mission (Succar et al., 2023). This suggests that the digital divide affecting pesantren is less about cultural resistance and more about access and design. The findings reflect a broader educational transformation in which traditional institutions are beginning to recognize digital competence as an essential 21st-century skill. The ability of santri to adapt quickly to low-cost EdTech tools demonstrates that pesantren learners possess strong intrinsic motivation when provided with accessible resources.

The positive reception from kyai and ustadz indicates a shift in institutional attitudes toward EdTech (Srivastava & Haghi, 2023). This suggests that pesantren leadership is open to innovations that enhance instructional organization, reduce workload, and improve student outcomes. These signals point to an evolving mindset among religious educators regarding technology. The success of low-cost EdTech in pesantren reflects the growing global awareness that educational inclusion depends not on high-end technology but on context-appropriate design. This finding becomes a marker of how traditional learning spaces can be transformed through thoughtful, culturally aligned approaches.

The findings imply that pesantren digitalization can be achieved at minimal cost, providing a practical pathway for thousands of traditional institutions to enhance the quality of their educational services. This democratizes access to digital literacy skills, preventing santri from being left behind in the national digital transformation agenda. The study suggests that policymakers should consider low-cost, scalable technologies when designing national EdTech initiatives targeting religious or rural schools (Al-Smadi et al., 2023). The success of offline tools and open-source learning platforms highlights the need for inclusive, bandwidth-independent solutions in educational policy.

The implications for educational practice include restructuring teaching methods to incorporate self-paced learning, peer-supported digital collaboration, and blended instructional models (Barashkin et al., 2023). Teachers gain opportunities to optimize lesson time, monitor progress more efficiently, and diversify learning activities through simple digital resources. The broader implication is that pesantren can serve as models for community-based digital

education in resource-constrained environments. Their successful adoption of low-cost EdTech demonstrates that digital innovation can align with cultural values and religious identities, offering lessons for other traditional education systems globally.

The results emerge because the EdTech tools were specifically designed to accommodate the constraints of pesantren environments, such as limited internet access and minimal device availability. By prioritizing offline accessibility and simple interfaces, the intervention aligned with the actual capabilities of the institutions. The improvements in autonomy are explained by the structured nature of digital modules, which guide santri through learning sequences independently (Cohen & Cohen, 2023). Digital tasks provide clear pathways for self-regulated learning, reducing reliance on teacher supervision and encouraging personal responsibility.

The substantial increase in digital literacy is due to repeated exposure to interactive materials and practice-based learning (Herrera Cano et al., 2023). Santri learned digital skills naturally while engaging with assignments and activities rather than through abstract instruction. The hands-on nature of the tools accelerated competence. The varying outcomes across pesantren correlate with differences in teacher readiness and leadership support. Pesantren with proactive involvement from ustadz and kyai provided stronger guidance, encouragement, and modeling for santri, explaining their higher performance gains.

The study points toward the need for systematic development of low-cost EdTech frameworks tailored specifically for pesantren. Institutions can adopt standardized guidelines for selecting appropriate technologies, designing offline learning content, and integrating digital tasks into traditional pedagogies (Biju et al., 2023). Future initiatives must prioritize teacher training programs that focus on practical operational skills and pedagogy-driven use of technology. Training should be contextualized to pesantren routines and responsibilities to ensure sustained adoption.

Policymakers should consider funding micro-level technological enhancements such as local servers, shared devices, and open-source platform development. These investments are minimal yet have high potential impact on the learning ecosystem within pesantren. Further research is needed to examine long-term effects of digitalization on santri academic achievement, social behavior, and spiritual practices (Garcia et al., 2023). Studies should explore scalability, community acceptance, and the sustainability of EdTech models across diverse pesantren typologies.

CONCLUSION

The most significant finding of this study is that meaningful digital transformation in traditional pesantren can be achieved through low-cost, context-responsive EdTech solutions that align with existing pedagogical and cultural practices. The research demonstrates that substantial improvements in santri autonomy and digital literacy do not require expensive infrastructure or high-end technologies; rather, they emerge from strategic integration of simple tools such as offline learning modules, modular LMS components, and mobile-based digital worksheets. This distinguishes the study from prior modernization efforts that often assume technological progress depends on advanced hardware and high-bandwidth environments. The evidence shows that when EdTech design is grounded in pesantren traditions, even minimal digital interventions can transform learning behaviors and instructional processes.

The study contributes a dual value proposition by offering both conceptual and methodological advancements for digitalizing pesantren. Conceptually, the research introduces a culturally aligned EdTech model that integrates Islamic boarding school values with contemporary digital learning principles, providing a framework that supports autonomy, structured learning, and digital competence without eroding pesantren identity. Methodologically, the study develops an iterative, low-cost EdTech design protocol involving needs assessment, prototype development, offline testing, and collaborative refinement with

teachers and santri. This procedure serves as a practical blueprint for other resource-limited educational institutions seeking to adopt scalable and sustainable digital tools.

The study is limited by its relatively short intervention period and focus on a small number of pesantren, which may restrict the generalizability of the findings across diverse pesantren ecosystems. Variations in teacher readiness, leadership support, and technological baselines also influence the outcomes, indicating that different pesantren may require differentiated implementation strategies. The absence of long-term evaluation makes it difficult to assess sustained effects on academic achievement, social interaction, and spiritual practices. Future research should explore longitudinal impacts of low-cost EdTech integration, investigate scalability across pesantren with varied typologies, and examine teacher professional development models that support digital-pedagogical competence. Further studies should also include community perceptions to ensure holistic acceptance and sustainability of digitalization efforts.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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