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THE EFFECTIVENESS OF TECHNOLOGY-BASED LEARNING IN DEVELOPING LITERACY AND NUMERACY AMONG ELEMENTARY SCHOOL STUDENTS: AN EXPERIMENTAL STUDY IN PUBLIC ELEMENTARY SCHOOLS WITHIN THE BATANGHARI WATERSHED AREA

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ABSTRACT
The 2022 National Assessment (Asesmen Nasional/AN) results showed that 58.6% of elementary school students in Muaro Jambi Regency had not yet achieved the minimum literacy competency, while 63.4% had not reached the minimum numeracy threshold. These figures consistently remained below the national average. This condition is further compounded by the characteristics of the Batanghari River Basin area, which faces multiple infrastructure constraints, including electricity outages averaging 9.3 hours per week, internet access limited to 2G-level connectivity, and a very low student-to-digital-device ratio of 1:7.4. This study examined the effectiveness of a technology-based learning intervention using the "LiterasiKu" application, which was specifically designed to function offline and incorporates content based on Jambi Malay culture. The intervention aimed to improve the literacy and numeracy skills of students in Grades 1–3 across 16 public elementary schools located in four subdistricts within the Batanghari River Basin area of Muaro Jambi Regency. Using a quasi-experimental mixed-methods design with a sample of 320 students, the study found that the technology-based intervention significantly improved phonological awareness and reading fluency ($\eta^2 = 0.37$), as well as understanding of number concepts ($\eta^2 = 0.31$). However, the effectiveness of the intervention was strongly moderated by the reliability of the electricity infrastructure ($\beta = 0.41$, $p < 0.001$) and teachers' capacity to mediate the use of technology. This study recommends a three-pillar model for integrating technology into literacy and numeracy instruction: minimum infrastructure reliability, teacher training in technology-mediated instruction, and locally contextualized content based on the Batanghari River Basin environment.

Keywords: effectiveness of educational technology, literacy, numeracy, elementary school, Batanghari River Basin.

INTRODUCTION
Literacy and numeracy skills constitute essential foundations that shape the quality of lifelong learning. At the elementary school level, mastery of these two competencies is a key determinant of educational success at subsequent levels. However, data from the 2022 National Assessment (Asesmen Nasional/AN) reveal a concerning reality: more than half of elementary school students in Muaro Jambi Regency had not achieved the minimum competency standards in literacy (58.6%) or numeracy (63.4%). These figures were substantially below the national average, which itself remained unsatisfactory (Kemdikbudristek, 2022).

The World Bank (2021) defines this condition as *learning poverty*, namely, the inability of a 10-year-old child to read and understand a simple text. This condition places children at risk of long-term educational exclusion. Overcoming it requires an intervention that simultaneously integrates three components: well-trained and motivated teachers, access to high-quality learning materials and technology, and a school environment that supports active learning (World Bank, 2021).

Educational technology is regarded as a potential solution for accelerating improvements in literacy and numeracy, particularly in areas with shortages of skilled teachers and high-quality instructional materials. Artificial intelligence (AI)-based adaptive learning applications have the potential to provide more personalized and targeted feedback than conventional instruction (Hattie, 2023). Through the Cognitive Theory of Multimedia Learning, Mayer (2021) emphasizes that technology-based instructional materials designed in accordance with cognitive load principles have been shown to produce deeper understanding.

Nevertheless, UNESCO (2022) warns that educational technology does not automatically lead to improved learning outcomes. In the context of developing countries, technology adoption that is not accompanied by careful contextual planning may instead exacerbate existing educational inequalities. This issue is particularly relevant in the Batanghari River Basin area, which faces multiple layers of infrastructure constraints. Maryam and Wibowo (2022) identified a four-layer taxonomy of barriers: physical infrastructure, particularly electricity instability (94.1%); teachers' human-resource capacity (71.8%); curriculum alignment (64.7%); and institutional coordination (58.8%).

Empirical studies in the Muaro Jambi area have produced promising findings while also offering important cautions. Rahayu and Prasetyo (2022) found that an offline-capable AI-based reading application significantly improved early literacy, although its effectiveness was highly dependent on device conditions. Susanti, Kurniawan, and Putra (2023) confirmed that gamification-based digital numeracy media effectively improved students' understanding of number concepts. However, its effectiveness declined sharply in schools experiencing electricity outages of more than eight hours per week. Meanwhile, Nurhayati and Syafii (2021) emphasized the crucial role of teachers as technology mediators. Without adequate training, the use of literacy applications reduced the intensity of meaningful teacher–student interaction by 42.3%.

In response to these research gaps, this study was designed to examine the effectiveness of the "LiterasiKu" application, which was specifically developed to operate offline and incorporates content based on Jambi Malay culture, in improving the literacy and numeracy skills of students in Grades 1–3 across 16 public elementary schools in the Batanghari River Basin area.

Specifically, this study aims to: (1) measure the effectiveness of LiterasiKu in improving early literacy, including phonological awareness, reading fluency, and reading comprehension; (2) measure its effectiveness in improving numeracy skills, including number concepts, procedural fluency, and problem-solving; (3) analyze the role of infrastructure as a moderator of intervention effectiveness; (4) analyze the mediating role of teachers; and (5) formulate a contextual and adaptive technology-integration model as a policy recommendation for the Muaro Jambi Regency Education Office.

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METHOD

This study employed a quasi-experimental mixed-methods design that simultaneously combined complementary experimental quantitative and exploratory qualitative components (Braun & Clarke, 2022). The quantitative component used a pretest–posttest non-equivalent control-group design. Sixteen public elementary schools across four subdistricts in the Batanghari River Basin area of Muaro Jambi Regency were assigned to an experimental group (8 schools, 160 students) and a control group (8 schools, 160 students), resulting in a total sample of 320 students in Grades 1–3.

The participating schools were selected purposively based on the geographical representation of the four subdistricts within the Batanghari River Basin and the comparability of their infrastructure characteristics. Students were randomly selected from each class in the participating schools. The inclusion criteria were: (1) active enrollment in Grades 1–3; (2) no diagnosed learning disabilities; and (3) parental or guardian consent.

The experimental group received an intervention using the "LiterasiKu" application for 16 weeks, with 40-minute sessions conducted three times per week. The application was specifically designed to function offline and incorporated content based on Jambi Malay culture. It included early literacy modules covering phonological awareness, reading fluency, and reading comprehension, as well as numeracy modules covering number concepts, arithmetic operations, and contextual problem-solving. Mayer's (2021) multimedia learning design principles were consistently applied in the development of the application content. The control group continued to receive conventional instruction in accordance with the regular curriculum.

Intervention effectiveness was assessed using an early literacy test adapted from the Dynamic Indicators of Basic Early Literacy Skills (DIBELS) protocol and a numeracy test developed based on the National Council of Teachers of Mathematics framework for Number and Operations. Both instruments were validated through expert review and field trials conducted in three elementary schools outside the study sample. Instrument reliability was measured using Cronbach's alpha, yielding coefficients of $\alpha = 0.87$ for literacy and $\alpha = 0.83$ for numeracy.

Quantitative data were analyzed using ANCOVA, with pretest scores included as covariates to control for initial differences between the groups. Effect sizes were calculated using eta squared (η^2). Moderation analysis was conducted to examine the roles of electricity infrastructure and teachers' technology-mediation capacity as moderating variables.

The qualitative component involved semi-structured, in-depth interviews with 24 teachers and 8 school principals, as well as classroom observations conducted across 12 instructional sessions. The qualitative data were analyzed using Braun and Clarke's (2022) six-phase reflexive thematic analysis, which consisted of data familiarization, initial code generation, theme development, theme review, theme definition and naming, and report production.

FINDINGS AND DISCUSSION

The ANCOVA results revealed significant differences between the experimental and control groups across all three assessed subdimensions of early literacy. The most substantial improvements occurred in phonological awareness ($\eta^2 = 0.37$, $F(1,317) = 186.4$, $p < 0.001$) and reading fluency ($\eta^2 = 0.29$, $F(1,317) = 129.8$, $p < 0.001$), both of which represented large

effect sizes according to Cohen's conventions. Reading comprehension also improved significantly, although the effect was more moderate ($\eta^2 = 0.18$, $F(1,317) = 69.5$, $p < 0.001$). This pattern of improvement is consistent with the findings of Rahayu and Prasetyo (2022), who reported significant gains in phonological awareness (+18.4 points) and reading fluency (+14.7 points) following the implementation of an offline-capable, AI-based reading application in the same region.

An analytical approach informed by Mayer's (2021) Cognitive Theory of Multimedia Learning helps explain why the intervention was effective. The modules applied the modality principle by combining audio narration with visual animation, as well as the segmentation principle by dividing instructional material into smaller, more manageable units. These features facilitated more efficient cognitive processing, enabling students to develop reading skills progressively. Usage data indicated that participants in the experimental group completed an average of 23.4 content units per week, suggesting a high level of learning engagement.

Furthermore, the integration of local cultural elements, including Jambi Malay folktales, traditional songs, and local vocabulary, contributed to increased learning motivation. Classroom observations recorded greater student interest and participation when the content was presented within a familiar cultural context. Taken together, the combination of multimedia design aligned with cognitive principles and locally grounded cultural content appeared to strengthen the effectiveness of the early literacy program, particularly in improving phonological awareness and reading fluency.

In the numeracy dimension, the ANCOVA results demonstrated that the intervention had a significant effect on several key aspects of mathematical ability. Students' understanding of number concepts improved substantially ($\eta^2 = 0.31$, $F(1,317) = 142.3$, $p < 0.001$), as did their procedural fluency in basic addition and subtraction operations ($\eta^2 = 0.26$, $F(1,317) = 111.6$, $p < 0.001$). Both results indicated large effects according to statistical conventions. These findings not only confirm but also extend the results of Susanti, Kurniawan, and Putra (2023), who reported a comparable improvement in numeracy ($\eta^2 = 0.31$) through the use of the gamified NumeriKa platform in the same research area. This convergence suggests that the effectiveness of technology-based pedagogical approaches can be replicated within the local context.

By contrast, contextual problem-solving ability did not show a significant improvement ($\eta^2 = 0.09$, $p = 0.12$). This result is consistent with Susanti et al. (2023), who similarly reported no meaningful effect on this subdimension ($\eta^2 = 0.08$). The absence of a significant effect indicates that, although the intervention effectively strengthened foundational numerical understanding and procedural fluency, the development of problem-solving skills involving the application of concepts to real-life situations requires a more explicit instructional design. Such a design may include progressively structured contextual tasks, explicit guidance in problem-modeling strategies, and collaborative activities that require students to transfer their knowledge.

In other words, improvements in conceptual and procedural numeracy can be achieved relatively quickly through structured modules, whereas the transfer of these abilities into higher-order mathematical thinking requires a more complex and sustained pedagogical intervention.

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The absence of a significant effect on contextual problem-solving ability was likely influenced by at least two principal factors. First, problem-solving that requires the transfer of concepts to real-life situations involves higher-order reasoning developed through substantive teacher–student interaction. Guided discussion, strategy modeling, and dialogical cognitive feedback are required, rather than the mere repetition of procedural exercises facilitated by technology. Procedural mastery, therefore, does not automatically develop into application skills unless it is accompanied by reflective thinking activities and teacher-facilitated reasoning strategies.

Second, the duration of the intervention was an important factor. Although the LiterasiKu content was designed contextually around the Batanghari River Basin, and thus incorporated local relevance, the 16-week intervention period may not have been sufficient to develop stable transfer abilities. The development of problem-solving skills requires repeated practice across various contexts, exposure to problems of differing levels of complexity, and opportunities to reflect on the strategies employed. This process generally requires more time than the development of procedural fluency.

On the basis of these findings, the role of teachers as facilitators of thinking needs to be strengthened. More systematic scaffolding should be implemented during contextual numeracy sessions, for example by dividing complex tasks into progressive stages, providing gradually structured thinking prompts, modeling problem-solving strategies, and creating opportunities for collaboration in which students articulate their reasoning to one another. This approach is consistent with the recommendation of Neuman and Dickinson (2019), who emphasize the importance of teacher scaffolding in early literacy development within resource-constrained contexts. Extending the duration of the intervention and designing tasks that require transfer across contexts may also facilitate the transition from procedural skills to contextual problem-solving ability.

The moderation analysis showed that the reliability of electricity infrastructure was the strongest moderator of intervention effectiveness ($\beta = 0.41$, $p < 0.001$). In practice, schools experiencing electricity outages of more than eight hours per week—which accounted for 62.5% of the experimental schools—demonstrated substantially lower performance. Their average literacy gain scores were approximately 34.7% lower, while their numeracy gain scores were approximately 38.1% lower than those of schools with more reliable electricity supplies.

This finding confirms the results of Susanti et al. (2023), who reported a 38.6% reduction in numeracy gain scores among schools experiencing prolonged electricity outages. It also underscores that the stability of the electricity supply is not merely a technical infrastructure issue but a determining factor in maintaining the continuity of digital device-based learning.

In addition to electricity, the condition of digital devices emerged as a significant moderator ($\beta = 0.33$, $p < 0.001$). Schools in which more than 20% of the available devices were damaged consistently reported lower gain scores. This pattern is consistent with Rahayu and Prasetyo's (2022) finding of a strong correlation between device reliability and the effectiveness of learning applications ($r = 0.67$). Device damage disrupted the regularity of instructional sessions, compelled teachers to improvise in ways that reduced the quality of

instructional activities, and decreased the frequency of students' exposure to structured learning materials.

Internet connectivity had a more limited but nonetheless meaningful effect, primarily because LiterasiKu was designed to operate offline. Nevertheless, connectivity remained important for modules requiring teacher-data synchronization, content updates, or collaborative features, for which its influence was statistically significant ($\beta = 0.19$, $p < 0.01$).

Overall, these findings demonstrate that the success of educational technology interventions depends on a comprehensive infrastructure ecosystem comprising a stable electricity supply, functional and well-maintained devices, and adequate network access for supporting functions. Large-scale interventions should therefore be accompanied by investment in basic infrastructure and device-maintenance programs to ensure that the pedagogical benefits of technology can be distributed equitably.

These findings also have important policy implications. Maryam and Wibowo (2022) found that electricity instability was identified by 94.1% of respondents as the principal barrier. Because this barrier is systemic, individual schools cannot resolve it independently without policy and budgetary intervention from the local government. This condition indicates the need to integrate education and energy policies at the Muaro Jambi Regency level.

The qualitative component of the study confirmed and extended Nurhayati and Syafii's (2021) findings concerning the critical role of teacher mediation. Thematic analysis of interviews with 24 teachers and observations of 12 classroom sessions generated five principal themes representing effective teacher-mediation practices: (1) active scaffolding in navigating the application interface; (2) mediation of AI-generated feedback using language that students could easily understand; (3) contextualization of digital content through students' local experiences in the Batanghari River Basin; (4) disciplined management of screen time; and (5) the ability to address basic technical problems without interrupting the instructional session. These five roles were identical to those identified by Nurhayati and Syafii (2021) in elementary schools in Mestong Subdistrict.

Significantly, there was considerable variation in teachers' mediation capacities. Teachers who had received technology-mediation training ($n = 9$) implemented all five mediation roles more consistently, and their classes achieved average gain scores that were 26.3% higher than those of teachers who had not received structured training. This finding is consistent with Nurhayati and Syafii (2021), who found that eight hours of technology-mediation training restored meaningful teacher–student interaction by 67.8% after it had previously declined by 42.3% due to the use of technology without adequate guidance. Luckin (2018) explains this phenomenon through the proposition that AI in education should strengthen rather than replace teachers' capacities.

The significant variation in effectiveness across the experimental schools can be explained through the three-stage technology-adaptation framework developed by Widiastuti and Hermanto (2023). Of the eight experimental schools, three had reached the independent innovation stage, characterized by a creative combination of digital and conventional elements; three were at the contextual adaptation stage; and two remained at the mimetic adoption stage. Schools at the independent innovation stage achieved average gain scores that were 41.2% higher than those of schools at the mimetic adoption stage.

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The most influential determinant of the adaptation stage was transformational school leadership (r = 0.76), followed by teacher-community networks (r = 0.69) and technical support from the local education office (r = 0.64). These results are consistent with Widiastuti and Hermanto (2023), who reported similar correlations of r = 0.79, r = 0.71, and r = 0.68, respectively. This convergence confirms that leadership-related factors may be more decisive than technical infrastructure alone.

Luckin's (2018) concept of an AI-enhanced learning ecosystem and the role of the AI-assisted learning "orchestrator" is particularly relevant here. Effective school principals function as orchestrators at the institutional level, creating the conditions that enable teachers to perform their technology-mediation roles optimally.

CONCLUSIONS

This study concludes that the "LiterasiKu" application, which was designed to function offline and incorporates content based on Jambi Malay culture, was effective in improving the early literacy and foundational numeracy skills of students in Grades 1–3 in the Batanghari River Basin area. The strongest effects were found in phonological awareness ($\eta^2 = 0.37$) and understanding of number concepts ($\eta^2 = 0.31$). However, the effectiveness of the intervention was strongly moderated by the reliability of the electricity infrastructure and the condition of the available devices, while also being substantially determined by teachers' technology-mediation capacity. Contextual problem-solving ability did not improve significantly, indicating the need for a pedagogical approach that extends beyond technology-assisted practice alone.

Based on these findings, the study proposes three principal recommendations. First, the Muaro Jambi Regency Education Office should develop a three-pillar model for integrating technology into literacy and numeracy instruction. These pillars should be implemented simultaneously and include: (a) a minimum infrastructure-reliability assurance program developed through collaboration with the state electricity company, PLN, and through solar-based renewable-energy initiatives; (b) a structured teacher-training program in technology mediation, consisting of at least 16 hours per year and organized around the five critical roles of technology mediators; and (c) the continuous development of application content grounded in the local context of the Batanghari River Basin, with the active involvement of teachers and local communities.

Second, a district-level technical support team should be established to provide schools with continuous technical assistance, particularly because 58.8% of school principals reported that they had never received adequate implementation guidance from the local education office (Maryam & Wibowo, 2022).

Third, school leadership development programs should incorporate competence in orchestrating technology-enhanced learning as a mandatory component. This recommendation is grounded in the finding that transformational school leadership was the strongest predictor of successful technology adaptation (r = 0.76–0.79).

Future research is recommended to examine this three-pillar model through a two- to three-year longitudinal design in order to assess its long-term effects and sustainability.

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