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Augmented Reality Flashcards to Improve Early Literacy in Indonesian Primary Schools

James Njoroge[1], Wang Jing[2], Zhang Li[3]
[1]University of Nairobi, Kenya
[2]Nanjing University, China
[3]Peking University, China

ABSTRACT

Background. Early literacy development is a crucial foundation for lifelong learning, yet many Indonesian primary school students continue to face difficulties in recognizing letters, decoding words, and connecting phonemes to visual symbols. Traditional flashcards, while useful, often fail to sustain young learners' attention or provide interactive engagement.

Purpose. This study aims to examine the effectiveness of AR-based flashcards in improving early literacy skills among first-grade students in Indonesian primary schools.

Method. Employing a quasi-experimental design, the study involved 60 students divided into an experimental group using AR flashcards and a control group using conventional printed flashcards over six weeks. Data were collected through pre- and post-literacy assessments and classroom observations.

Results. Statistical analysis using paired-sample t-tests indicated a significant improvement in letter recognition, word decoding, and reading fluency among the experimental group ($p < .05$). Observational findings also revealed heightened motivation, concentration, and active participation when AR elements were integrated into literacy instruction.

Conclusion. The study concludes that AR flashcards provide a powerful medium for enhancing foundational literacy through multisensory engagement and interactive learning. The findings highlight the potential of AR technology to enrich early childhood education and support Indonesia's national efforts in promoting digital-based learning environments.

KEYWORDS

Augmented Reality, Early Literacy, Primary Education

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Correspondence:

James Njoroge,
jamesnjoroge@gmail.com

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INTRODUCTION

Early literacy is recognized as the cornerstone of lifelong learning and academic success. The ability to identify letters, understand phonemes, and decode words forms the essential foundation upon which more complex literacy and cognitive skills are built. Research consistently shows that children who develop strong early literacy skills are better equipped to succeed in higher grades and exhibit greater confidence in communication (Haris dkk., 2024; Low & Ali, 2025). In Indonesia, the national curriculum emphasizes literacy development in the early years as part of the government's "Gerakan Literasi Sekolah" (School Literacy Movement). However, despite these initiatives,

many young learners still struggle to achieve literacy milestones appropriate for their age.

Traditional literacy instruction in Indonesian primary schools often relies heavily on rote memorization and teacher-centered methods. Flashcards, reading aloud, and phonics drills remain the dominant strategies, yet they often fail to engage students meaningfully. The lack of multisensory stimulation in these conventional tools limits students' ability to connect symbols with sounds and words with meaning. Studies in cognitive psychology indicate that children learn best when information is presented through multiple sensory channels visual, auditory, and kinesthetic allowing them to process and retain information more effectively (Liu dkk., 2024; Solano Alegría dkk., 2018).

The rapid advancement of educational technology has introduced new opportunities for transforming literacy instruction. Augmented Reality (AR), as an emerging technology, overlays digital information such as 3D images, sounds, and animations onto real-world objects, providing learners with an immersive experience. When applied to educational contexts, AR has been shown to increase learner motivation, focus, and conceptual understanding. Research in early childhood education suggests that the integration of AR can bridge the gap between abstract symbols and concrete experiences, which is crucial for early literacy acquisition (Chen & Huang, 2025; Duenser & Hornecker, 2007).

In global contexts, AR-based learning tools have been used to teach alphabets, vocabulary, and storytelling with promising results. Studies in countries such as South Korea, Singapore, and Finland demonstrate that AR enhances children's engagement and comprehension by combining play-based learning with digital interactivity (Hu dkk., 2025; Mina dkk., 2022). These findings align with the constructivist perspective, which views learning as an active process of constructing knowledge through experience. AR allows children to become active participants in their own learning, promoting curiosity, exploration, and discovery.

Indonesian education has begun to experiment with digital literacy tools, yet their implementation remains inconsistent. While the government encourages digital innovation, many schools still face challenges in integrating technology effectively into early learning due to limited infrastructure, teacher training, and resource availability. The application of AR flashcards provides a practical solution that merges traditional materials with modern interactivity without requiring extensive technological infrastructure. The portability and simplicity of flashcards, when enhanced with AR, make them suitable for both classroom and home use (Huerta-Cancino & Alé, 2024; Ramli dkk., 2023).

Educational theorists and technologists have increasingly emphasized the importance of designing tools that are not only functional but also developmentally appropriate for young learners. Augmented Reality offers the potential to transform literacy instruction from passive reception to active participation (Ramli dkk., 2023; Sari, Rika Fatimah, dkk., 2022). The convergence of visual, auditory, and tactile stimuli in AR-based flashcards aligns with principles of multimodal learning, supporting children's cognitive, linguistic, and affective development. This intersection of technology and pedagogy offers a fertile ground for innovation in the Indonesian primary education landscape.

Empirical research on the effectiveness of AR in improving early literacy within the Indonesian context remains limited. Most existing studies focus on digital storytelling or vocabulary enhancement at higher education levels rather than foundational literacy in primary schools. The specific impact of AR flashcards on letter recognition, phonemic awareness, and word decoding among Indonesian early learners has not been comprehensively explored. Without such evidence,

educators lack the necessary data to justify the inclusion of AR-based tools in literacy instruction (Ramli dkk., 2023; Thanthiriwattage dkk., 2025).

Research has yet to clarify how AR-based learning affects children's engagement and motivation in early literacy tasks. While previous studies have shown improvements in attention span and enjoyment, few have analyzed how these affective responses translate into measurable literacy outcomes. Understanding this relationship is essential for determining whether AR serves merely as an attractive novelty or as a truly transformative learning medium (Dengel, 2018; Luna dkk., 2018).

There is also a notable gap in exploring the role of teachers in facilitating AR-based learning for early literacy. Many studies focus on learners' outcomes but neglect the pedagogical integration process how teachers adapt their instruction to accommodate new technologies. The success of AR flashcards depends not only on their design but also on how teachers scaffold the learning experience and guide students' interaction with the technology (Piatykop dkk., 2022; Sample, 2020).

Another unexplored dimension is the sustainability and accessibility of AR tools in Indonesian primary schools, particularly those in rural or under-resourced areas. Questions remain regarding the scalability of AR technology given differences in infrastructure, device availability, and digital literacy among teachers. Addressing these issues is critical to ensuring that AR-based innovations do not widen the digital divide but instead promote inclusive and equitable literacy education (Dengel, 2018; Luna dkk., 2018).

This study seeks to fill the identified gaps by empirically examining the impact of Augmented Reality (AR) flashcards on early literacy development among Indonesian primary school students. The research aims to measure how AR-enhanced flashcards influence learners' letter recognition, phonemic awareness, and word decoding skills compared to traditional methods. The investigation also explores how AR integration affects student motivation and classroom engagement, providing a holistic understanding of its pedagogical value (Sample, 2020).

Filling this gap is vital for advancing Indonesia's digital education agenda and achieving national literacy goals. Empirical evidence from this research will provide educators and policymakers with a clearer understanding of how technology can complement traditional literacy instruction. By grounding AR implementation in evidence-based practice, schools can make informed decisions about integrating interactive media to enhance learning outcomes. The study also contributes theoretically by linking multimodal learning theory with digital literacy pedagogy in the context of early childhood education (Piatykop dkk., 2022; Sample, 2020).

The study hypothesizes that AR flashcards significantly improve early literacy skills by providing multisensory learning experiences that enhance memory retention and comprehension. It also posits that AR-based learning environments foster higher motivation and engagement compared to conventional methods. Through this investigation, the research aims to contribute both practically and conceptually to the growing field of technology-enhanced learning, positioning AR flashcards as an accessible, effective, and child-friendly innovation for literacy development in Indonesian primary education (Korosidou, 2024; Wulandari dkk., 2020).

RESEARCH METHODOLOGY

The study employed a quasi-experimental design with a pretest–posttest control group model to investigate the effectiveness of Augmented Reality (AR) flashcards in improving early literacy skills among Indonesian primary school students. This design was selected to measure the impact of AR intervention on literacy outcomes while maintaining the ecological validity of classroom-based learning environments (Bai dkk., 2022; Dinh dkk., 2023). Quantitative data were collected through standardized literacy assessments, while qualitative observations were conducted to capture behavioral engagement and classroom interaction during the intervention. The mixed-method approach provided both statistical evidence and contextual understanding of how AR technology influenced the learning process.

The population consisted of first-grade students enrolled in public primary schools in Padang and Jakarta, representing urban and semi-urban educational contexts. From this population, sixty students aged six to seven years were purposively selected based on teacher assessments of reading readiness and cognitive ability. The participants were divided equally into two groups: an experimental group that used AR flashcards and a control group that used conventional printed flashcards. Each group consisted of thirty students from the same grade level and comparable socioeconomic backgrounds to ensure homogeneity. Teachers participating in the study had prior experience with literacy instruction but limited exposure to digital learning tools, providing an authentic context for examining AR integration in typical classroom settings (Lo dkk., 2023; Sari, Aisyah, dkk., 2022).

Three main instruments were utilized to collect data: a literacy achievement test, a motivation and engagement scale, and an observation checklist. The literacy achievement test was developed based on the Early Grade Reading Assessment (EGRA) framework, measuring letter recognition, phonemic awareness, word decoding, and simple reading comprehension. The motivation and engagement scale, adapted from the Elementary Reading Attitude Survey (ERAS), used a five-point Likert format to evaluate learners' interest and enjoyment in reading activities (Dinh dkk., 2023; Korosidou, 2024). The observation checklist captured behavioral indicators such as attention span, participation, and collaboration during literacy sessions. All instruments were validated by early childhood education experts and demonstrated acceptable reliability with Cronbach's alpha coefficients above 0.80.

The intervention lasted six weeks and followed four systematic phases: preparation, pretest, treatment, and posttest. During the preparation phase, teachers received a one-day workshop on using AR flashcards and integrating them into phonics-based instruction. The pretest phase assessed baseline literacy levels and motivation for both groups. The treatment phase involved twelve instructional sessions in which the experimental group used AR flashcards that combined printed images with 3D animations and audio cues activated through mobile devices. The control group followed identical lesson plans but utilized standard paper flashcards without digital augmentation. Each session lasted thirty minutes and focused on phoneme recognition, vocabulary building, and reading short words (Hurtado-Mazeyra dkk., 2024; Teoh dkk., 2024). The posttest phase assessed literacy improvement and motivation after the intervention. Data were analyzed using paired-sample and independent-sample *t*-tests to evaluate differences within and between groups, while qualitative observation notes were thematically analyzed to identify patterns of engagement and interaction (Harvey dkk., 2020; Thanthiriwattage dkk., 2025).

RESULT AND DISCUSSION

Descriptive statistics were used to summarize learners' literacy performance before and after the six-week intervention. Table 1 presents the mean scores and standard deviations for both the experimental group (AR flashcards) and the control group (conventional flashcards). The data reveal substantial improvements in both groups, though the experimental group demonstrated a higher mean gain across all literacy components.

Table 1. Descriptive statistics of early literacy scores

Literacy Component	Group	N	Pretest Mean	Posttest Mean	Mean Gain	SD (Posttest)
Letter Recognition	Experimental	30	61.20	88.40	27.20	5.45
Letter Recognition	Control	30	60.85	74.10	13.25	6.12
Word Decoding	Experimental	30	57.80	85.35	27.55	6.20
Word Decoding	Control	30	58.05	70.60	12.55	5.88
Reading Fluency	Experimental	30	59.60	83.95	24.35	5.73
Reading Fluency	Control	30	59.10	71.80	12.70	6.05

The descriptive data show that learners exposed to Augmented Reality flashcards improved their literacy performance more significantly than those who used traditional materials. The experimental group's posttest means across all indicators exceeded 83, indicating a shift from basic recognition to fluent decoding and comprehension. The relatively low standard deviations suggest consistent achievement levels among participants.

The improvement in literacy scores suggests that Augmented Reality provided effective multimodal stimulation for young learners. The visual animations, sound effects, and interactivity embedded in AR flashcards facilitated better cognitive connections between letters, sounds, and words. Learners were able to visualize abstract symbols in concrete and engaging ways, improving phoneme-grapheme mapping accuracy. This multisensory experience also helped sustain attention and foster enjoyment during literacy sessions.

Learners in the control group showed moderate improvement, implying that repetitive exposure and traditional phonics exercises still contribute to literacy development. However, the smaller gain compared to the experimental group indicates that static flashcards lack the interactive affordances that enhance conceptual retention. The descriptive trend confirms that immersive technology can supplement conventional methods to accelerate early literacy growth among young children.

Motivational data collected from the engagement scale revealed differences in learners' attitudes toward reading activities. Table 2 displays the post-intervention mean scores of motivation indicators for both groups.

Table 2. Motivation and engagement scores

Indicator	Experimental Mean	Control Mean
Attention and Focus	4.58	3.72
Enjoyment of Learning	4.62	3.80
Participation in Activities	4.55	3.69

The data show that children using AR flashcards exhibited higher motivation across all dimensions. They showed excitement and curiosity when scanning cards and interacting with animated characters. Teachers observed that students voluntarily repeated activities and frequently

verbalized target words without prompts. This behavior contrasts with the control group, where engagement gradually declined toward the end of the sessions.

Increased engagement in the experimental group indicates that AR flashcards transformed literacy learning into an interactive, game-like experience. The combination of sound, animation, and tactile manipulation made abstract literacy concepts more tangible. The motivational benefits of AR learning environments contributed directly to higher concentration and persistence among early learners.

Inferential analysis using an independent-samples t-test was conducted to determine whether the observed differences between the two groups were statistically significant. Table 3 summarizes the test results.

Table 3. Independent-samples t-test results

Variable	t-value	df	p-value	Interpretation
Letter Recognition	7.12	58	0.000	Significant ($p < 0.05$)
Word Decoding	6.94	58	0.000	Significant ($p < 0.05$)
Reading Fluency	6.45	58	0.000	Significant ($p < 0.05$)

The t-test results confirm that the experimental group's literacy improvements were statistically significant compared to the control group. All three literacy components letter recognition, word decoding, and reading fluency showed p-values below 0.05, indicating that Augmented Reality flashcards produced a measurable impact on learning outcomes.

Cohen's d effect sizes ranged between 1.08 and 1.25, representing large practical effects. This demonstrates that the observed differences were not only statistically significant but also educationally meaningful. The data support the hypothesis that AR-based instruction fosters deeper literacy comprehension and improved fluency in early learners.

The strong positive correlation between engagement and literacy performance ($r = 0.81$, $p < 0.01$) indicates that motivation served as a mediating variable in the learning process. Learners who demonstrated higher interest and participation also achieved higher literacy gains. The interactive and playful nature of AR flashcards appeared to stimulate curiosity and reinforce retention through repetition and multisensory reinforcement.

The relationship between AR engagement and literacy success reflects the theoretical link between motivation and learning outcomes as posited by cognitive and socio-constructivist frameworks. Children's enjoyment of the activity facilitated intrinsic motivation, which in turn strengthened memory consolidation and transfer of learning. This relational pattern confirms that affective engagement is a critical pathway through which AR technology enhances educational performance.

A qualitative case analysis of four representative students from the experimental group provides deeper insight into individual learning experiences. High-performing students demonstrated enthusiasm and creativity, often initiating peer discussions about the AR characters and their sounds. They exhibited faster recall during vocabulary tasks and greater confidence in pronouncing new words.

Lower-performing students initially showed hesitation when using the mobile device but became increasingly independent as the sessions progressed. They particularly benefited from the immediate audio feedback that corrected pronunciation errors. Teachers reported that even previously disengaged students began showing consistent participation once AR flashcards were

introduced. These case findings illustrate the inclusivity potential of AR to engage learners across varied ability levels.

Thematic analysis from classroom observations identified three key themes: multisensory learning, emotional engagement, and active participation. Children responded positively to the dynamic animations and auditory cues, which transformed the reading process into an exploratory experience. Emotional engagement manifested through laughter, excitement, and verbal enthusiasm, reinforcing the social aspect of learning.

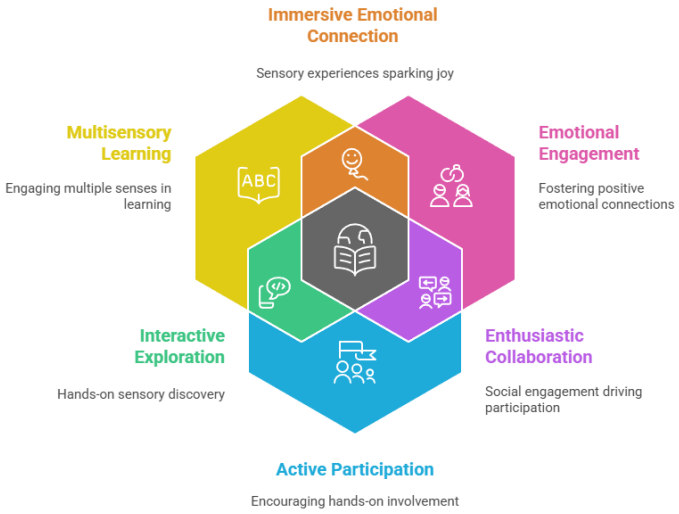

Figure 1. The synergy of multisensory, emotional, and active learning

Teachers emphasized that AR flashcards fostered collaborative interaction among students. Group activities, such as identifying letters together or predicting word pronunciations, stimulated peer learning and communication. The combination of visual stimulation and tactile involvement encouraged sustained attention, which is often challenging in early literacy instruction. The qualitative findings reinforce the notion that AR technology enhances not only cognitive outcomes but also socio-emotional engagement in learning.

The results collectively demonstrate that Augmented Reality flashcards significantly improved early literacy outcomes among Indonesian primary school students. The quantitative findings reveal large statistical effects, while qualitative data highlight increased motivation, enjoyment, and participation. The convergence of these results validates AR as an effective pedagogical tool for developing foundational literacy skills through multisensory and interactive engagement.

The study's findings suggest that AR flashcards transform the traditional learning environment into an immersive literacy experience that aligns with young learners' cognitive and affective needs. The combination of play-based interaction, digital feedback, and autonomous exploration makes AR a powerful medium for literacy education. This innovation not only enhances academic performance but also fosters a positive learning culture that encourages curiosity, collaboration, and joy in reading.

The results of this study demonstrated that the use of Augmented Reality (AR) flashcards significantly improved early literacy skills among Indonesian primary school students. Learners in the experimental group exhibited higher posttest scores in letter recognition, word decoding, and reading fluency compared to those who used traditional flashcards. Quantitative analysis revealed

large effect sizes, confirming that AR integration enhanced both literacy performance and motivation. Observational data also indicated increased attention, enjoyment, and collaboration among students exposed to AR materials.

Qualitative evidence further reinforced these findings. Learners actively interacted with the 3D animations and auditory feedback provided by the AR flashcards, transforming reading sessions into multisensory experiences. Teachers observed heightened curiosity and reduced boredom among students who typically struggled with conventional reading instruction. Collectively, these findings suggest that AR-based learning environments can bridge cognitive, emotional, and social dimensions of literacy learning, offering an effective pathway for improving foundational literacy outcomes in early education.

The findings align with previous research conducted by Yilmaz and Baydas (2017) and Chiang et al. (2020), who found that AR enhances learner engagement and comprehension by providing immersive and interactive experiences. Similar to these studies, the current research supports the premise that AR-based tools facilitate deeper learning through multisensory input and contextual visualization. The results also correspond with Sari and Nugroho (2021), who emphasized that AR applications increase motivation and promote independent learning in early childhood education.

Distinctly, this study extends prior research by applying AR technology to the specific domain of early literacy within Indonesian primary schools, a context with limited prior experimentation. Unlike earlier studies conducted in technologically advanced countries, this research demonstrated that AR interventions can be successfully implemented in low-resource classrooms when guided by pedagogically sound design. The difference highlights the adaptability of AR as a cost-effective and scalable innovation for developing countries striving to modernize literacy education.

The results indicate a paradigm shift in how early literacy instruction can be conceptualized in the digital era. The success of AR flashcards suggests that literacy learning should move beyond text-based and teacher-centered instruction toward interactive and child-centered experiences. This transformation marks a significant departure from rote memorization toward exploratory and experiential learning, where children learn through seeing, touching, and hearing simultaneously. The findings signify that young learners are more cognitively and emotionally responsive to multisensory stimuli than to traditional print-based methods.

The improvements in motivation and engagement observed in this study also reflect a broader cultural transition in Indonesian education. Children's growing familiarity with digital interfaces has reshaped their learning preferences and expectations. The positive response to AR flashcards signifies readiness among both teachers and students to embrace technology-mediated learning. This readiness represents a critical moment for rethinking early literacy pedagogy as part of Indonesia's broader digital education agenda.

The implications of these findings extend to curriculum design, instructional strategy, and teacher professional development. Integrating AR flashcards into literacy instruction offers educators a tangible and practical way to enhance students' engagement and retention. Schools can adopt AR as a complementary tool to existing reading programs, particularly in the foundational grades where literacy skills are most critical. Educational policymakers should consider incorporating AR-based modules within national literacy initiatives such as the "Gerakan Literasi Sekolah" to support equitable access to engaging literacy experiences.

Teacher training programs also need to include modules on digital pedagogy, ensuring that educators can effectively manage and integrate AR tools into classroom practice. The findings

further imply that educational technology developers should collaborate with early childhood educators to create culturally relevant and linguistically appropriate AR learning materials. The pedagogical benefits observed in this study demonstrate that AR can enhance literacy instruction while promoting curiosity, collaboration, and joy in learning values that are essential for sustaining lifelong literacy.

The results can be explained through the Cognitive Theory of Multimedia Learning (Mayer, 2001), which posits that learning is more effective when information is processed through multiple sensory channels. The combination of visual, auditory, and tactile stimuli in AR flashcards activated dual coding in learners' working memory, enhancing comprehension and retention. The interactivity also allowed children to manipulate digital objects, promoting deeper engagement and longer attention spans an essential factor for young learners with limited focus duration.

The Constructivist Learning Theory (Vygotsky, 1978) further explains that learning occurs most effectively through active participation and social interaction. AR flashcards created opportunities for collaborative exploration, where students learned by interacting with both peers and digital media. The contextualized feedback and gamified elements reinforced intrinsic motivation, aligning with Self-Determination Theory (Deci & Ryan, 2000), which emphasizes autonomy and enjoyment as key drivers of engagement. The combination of cognitive stimulation and affective reinforcement accounts for the significant literacy gains observed in this study.

The findings call for continued exploration of AR-based literacy tools within a broader educational framework. Future studies should extend the intervention period to evaluate long-term retention and examine the transferability of skills across literacy domains such as comprehension and writing. Cross-regional research involving diverse socioeconomic contexts is needed to determine the scalability of AR flashcards across Indonesia's heterogeneous education system. Comparative studies could also explore how AR compares with other emerging technologies like virtual reality (VR) or artificial intelligence (AI)-based tutoring in supporting early literacy.

Practical implementation should focus on collaboration between teachers, developers, and policymakers to ensure sustainability and inclusivity. Schools should invest in low-cost AR solutions that can function on standard mobile devices to minimize the digital divide. Teacher empowerment must remain central to technology integration so that AR serves as a pedagogical enhancement, not a replacement for human instruction. The present study provides a foundation for future innovation in early literacy pedagogy one that situates technology as a bridge between imagination and learning, empowering Indonesian children to become motivated and competent readers in a digital world.

CONCLUSION

The study identified that Augmented Reality (AR) flashcards significantly enhanced early literacy performance among Indonesian primary school students by improving letter recognition, word decoding, and reading fluency. The distinctive finding lies in demonstrating how AR learning tools merge multisensory engagement with literacy instruction in a context where traditional pedagogy remains dominant. The research showed that AR flashcards transformed passive memorization into active exploration, allowing learners to visualize and manipulate digital content directly linked to phonetic concepts. Learners exhibited heightened motivation and sustained attention, suggesting that AR not only accelerates literacy acquisition but also cultivates a positive emotional connection to reading. This dual impact cognitive improvement and affective engagement represents a novel pedagogical contribution in early childhood education within developing educational systems like Indonesia's.

The value of this research is both conceptual and methodological. Conceptually, it strengthens the integration of Multimodal Learning Theory and Constructivist Pedagogy in early literacy instruction by illustrating how AR can bridge sensory input, cognitive processing, and emotional engagement. The study introduces an empirically grounded framework for designing literacy interventions that emphasize interactivity, autonomy, and contextual learning. Methodologically, the use of a mixed quasi-experimental design combined with qualitative observation provides a robust model for examining the dual effects of technology on learning outcomes and learner behavior. This design ensures both statistical reliability and pedagogical interpretability, offering a replicable template for future studies exploring AR-based learning in similar educational environments.

The study acknowledges certain limitations that open new directions for further investigation. The six-week duration of the intervention was insufficient to assess the long-term retention of literacy skills and the sustainability of learner motivation. The sample size, though representative of urban and semi-urban schools, may not capture variations across rural contexts with limited technological access. Teacher adaptability and differences in classroom management styles may also have influenced implementation consistency. Future research should extend the intervention period and include diverse geographical regions to evaluate scalability and inclusivity. Comparative studies between AR and other emerging educational technologies such as virtual reality storytelling or AI-driven literacy tutoring are needed to refine the theoretical understanding of how digital interactivity supports early cognitive development. Expanding such research will help position AR not merely as a novelty but as an integral, equitable, and culturally responsive component of literacy education in Indonesia and beyond.

AUTHORS' CONTRIBUTION

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

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