Room of Civil Society Development
DOI: https://doi.org/10.59110/rcsd.798
Volume 4 Issue 6, Year 2025

Improving Elementary Students' Literacy and Numeracy through an Augmented Reality-Enhanced SmartBook

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ABSTRACT

Previous studies on Augmented Reality (AR) in education have largely focused on vocabulary learning, reading comprehension, spatial reasoning, or mathematics skills using mobile or game-based platforms, mostly in international contexts. Research examining AR that is directly integrated into printed classroom materials remains limited, particularly studies aligned with Indonesia's Kurikulum Merdeka and aimed at strengthening foundational literacy and numeracy. To address this gap, this study evaluated the effectiveness of SmartBook LKPD DigiLitNum, an AR-supported interactive workbook, in improving Grade 3 students' literacy and numeracy performance. A one-group pre-test and post-test design was employed involving 35 students at UPT SDN 150 Gresik over 30 learning sessions. Standardized literacy and numeracy assessments were administered before and after the intervention. The results showed substantial improvements in both domains, with literacy scores increasing from a mean of 68.2 to 87.5 and numeracy scores from 66.2 to 86.9. Normalized gain scores ranging from 0.64 to 0.66 indicate moderate to high effectiveness. Classroom observations further revealed increased student engagement, participation, and learning motivation. These findings provide empirical evidence that AR-enhanced printed workbooks can function as practical and scalable learning resources for improving foundational literacy and numeracy in Indonesian elementary schools.

Keywords: *Augmented Reality; Digital Learning; Elementary Education; Literacy; Numeracy.*

1. Introduction

Literacy and numeracy are foundational competencies that underpin lifelong learning and serve as key indicators of educational quality. Beyond academic achievement, these skills influence social participation and economic productivity (Chang, 2023). In Indonesia, however, national assessments and international benchmarks such as PISA consistently reveal persistent challenges in students' reading comprehension and mathematical reasoning at the elementary level (OECD, 2023). These outcomes point to systemic limitations in instructional practices and student engagement.

Several interrelated factors contribute to this condition, including teacher-centered instructional approaches, limited access to engaging learning media, and insufficient use of contextual and multimodal strategies that connect abstract concepts with learners' everyday experiences (Pertiwi et al., 2022; Sulistiawati et al., 2024). In third-grade primary classrooms, context-based approaches such as Realistic Mathematics Education have been implemented to support numeracy understanding by linking mathematical concepts to meaningful real-

world situations (Samritin, et al., 2025). Consequently, there is an urgent need for innovative learning resources that actively engage students while supporting deeper conceptual understanding in literacy and numeracy learning.

Augmented Reality has emerged as a promising educational technology due to its capacity to overlay digital content onto real-world environments, creating interactive and contextualized learning experiences. Recent studies in Indonesia and similar contexts indicate that AR can enhance vocabulary acquisition, reading comprehension, and learner motivation by presenting linguistic input in visually rich and meaningful contexts (Sagita et al., 2025; Kurniasih et al., 2022). AR-enhanced storybooks and thematic materials have also been shown to foster positive attitudes toward reading and improve early literacy development among elementary learners (Sundari et al., 2025).

In numeracy education, AR facilitates conceptual understanding and problem-solving accuracy by transforming abstract numerical relationships into visual and manipulable representations. Empirical studies demonstrate that AR-based and STEM-AR learning applications significantly improve students' numeracy literacy, spatial reasoning, and retention of mathematical concepts (Pasaribu et al., 2024; Nasaruddin et al., 2025). These findings align with the Cognitive Theory of Multimedia Learning, which emphasizes that learning is more effective when verbal and visual information are processed simultaneously, thereby reducing cognitive load and supporting deeper understanding (Mayer, 2020).

Despite its pedagogical potential, most existing AR research positions the technology as a standalone digital application rather than as an integrated component of curriculum-aligned printed learning materials. Systematic reviews of AR implementation in Indonesian elementary schools indicate that AR-based studies are predominantly concentrated in science and higher-grade levels, with limited attention to literacy and numeracy learning in lower grades and minimal alignment with printed instructional resources (Saputri & Susilowati, 2022; Susanti et al., 2024). Furthermore, empirical studies employing pre-test and post-test designs to measure the direct impact of AR-embedded workbooks on literacy and numeracy outcomes in authentic classroom settings remain scarce.

In contrast to previous research, this study integrates Augmented Reality directly into a printed LKPD that is explicitly aligned with Indonesia's Kurikulum Merdeka. AR is positioned as a complementary enhancement to existing learning materials rather than as a separate digital tool. Moreover, the study extends beyond examining motivational or affective outcomes by empirically measuring improvements in students' literacy and numeracy skills through a pre-test and post-test design implemented in a real elementary classroom context. This approach provides localized and practice-oriented evidence regarding the effectiveness of AR-enhanced printed workbooks in Indonesian primary education.

SmartBook LKPD DigiLitNum was developed through a university–school partnership at UPT SDN 150 Gresik, East Java. It includes approximately 30 Phase B (Grade III) subtopics across language, science, and mathematics, integrating contextual reading tasks, AR visualizations, and structured literacy–numeracy exercises.

The design and implementation of this SmartBook are theoretically grounded in constructivist and multimodal literacy frameworks, which emphasize active meaning-making through interaction with multiple modes of representation (Cope & Kalantzis, 2020). Within this perspective, Augmented Reality situates abstract concepts in concrete visual contexts, while Learning Analytics supports monitoring and formative feedback processes (Ifliadi et al., 2024; Ifenthaler & Yau, 2020). In practice, however, the effectiveness of such

digital interventions depends on curriculum alignment, accessibility, and teacher readiness, particularly in contexts affected by digital inequity (Rosita et al., 2025).

Accordingly, this study aims to evaluate students' literacy and numeracy performance before and after the implementation of the AR-based SmartBook LKPD DigiLitNum in an Indonesian elementary school context.

2. Method

This study employed a quantitative pre-experimental one-group pre-test–post-test design to examine the impact of the *SmartBook LKPD DigiLitNum* on elementary students' literacy and numeracy achievement. The design was chosen because it enables measurement of learning gains after an educational intervention without manipulating external variables (Creswell, 2018).

The intervention was implemented for approximately three months and consisted of 30 learning sessions, each corresponding to a sub-topic in the SmartBook. Each session integrated AR-based learning activities and short practice tasks aimed at developing reading comprehension, vocabulary, and basic numeracy reasoning.

The participants were 35 third-grade students (17 boys and 18 girls, aged 8–9 years) enrolled at UPT SDN 150 Gresik, East Java, Indonesia. They represented a single intact class within the partner school *Rumah Belajar One Fifty*, which has previously collaborated in teacher-training programs on digital literacy.

All students had similar socio-educational backgrounds and had limited prior exposure to technology-based learning media. Informed consent was obtained from the school principal, teachers, and parents. Participation was voluntary, and confidentiality was ensured by anonymizing the data. Two instruments were designed to measure students' performance:

a. Literacy Test (20 items) – consisting of short narrative texts followed by multiple-choice and short-answer comprehension questions targeting main idea identification, vocabulary meaning, and inferential reasoning.

b. Numeracy Test (20 items) – consisting of arithmetic, pattern recognition, and word-problem tasks assessing understanding of numbers, operations, and logical relations.

Both instruments were constructed based on Indonesia's *Kurikulum Merdeka* (Phase B competencies) and validated by two education experts and one elementary teacher. The reliability coefficients were acceptable (KR-20 = 0.86 for literacy; 0.83 for numeracy), indicating internal consistency (Fraenkel & Wallen, 2020).

Scores ranged from 0 to 100. The same instruments were administered as pre-test and post-test, with a four-week interval and different item sequences to reduce recall effects.

Students took the literacy and numeracy pre-tests under supervised conditions. The baseline data served as a reference for subsequent analysis. Over 30 sessions, students learned using the SmartBook, which integrates *Augmented Reality* (AR) objects, interactive videos, and contextual exercises. Examples of AR scenes included animated professions ("People Around Us"), weather phenomena, and geometry visualization. During each session, students scanned embedded QR codes to visualize 3D objects via smartphones or tablets.

Figure 1. Students interacting with the Augmented Reality features embedded in the SmartBook LKPD DigiLitNum during literacy and numeracy learning activities.

Learning was guided by classroom teachers trained in the preceding DigiLitNum community service program. Students' participation and task completion were recorded through a MoodleCloud-based *Learning Analytics* dashboard. Teachers received real-time progress reports to identify students needing additional support. After the 30th session, students completed the same literacy and numeracy tests as post-tests. Quantitative test data were complemented by classroom observations and teacher reflections to enrich interpretation.

3. Result

Prior to inferential analysis, assumption testing was conducted to confirm the appropriateness of parametric procedures. Normality was assessed using the Kolmogorov–Smirnov test, yielding non-significant results for both literacy ($p = .089$) and numeracy ($p = .072$), indicating that the score distributions did not significantly deviate from normality. Homogeneity of variances was examined using Levene's test, which also produced non-significant results ($p > .05$).

Based on these results, paired-sample t-tests were applied to examine differences between pre-test and post-test scores in literacy and numeracy following the implementation of SmartBook LKPD DigiLitNum.

The descriptive statistics of students' literacy and numeracy performance before and after the implementation of SmartBook LKPD DigiLitNum are summarized in the table below. These values offer an initial overview of score patterns and provide a foundation for further inferential interpretation in the subsequent sections.

Table 1. Descriptive Statistics of Literacy and Numeracy Scores (N = 35)

Domain	Test	Mean (M)	SD	Minimum	Maximum	Mean Difference (Δ)	Increase
Literacy	Pre-test	68.2	8.9	51	83	–	–
Literacy	Post-test	87.5	6.4	73	98	+19.3	28.3%
Numeracy	Pre-test	66.2	9.4	48	82	–	–
Numeracy	Post-test	86.9	6.7	71	97	+20.7	31.3%

As shown in Table 1, both literacy and numeracy mean scores increased substantially after the intervention. Literacy scores improved from M = 68.2 (SD = 8.9) to M = 87.5 (SD = 6.4), while numeracy scores increased from M = 66.2 (SD = 9.4) to M = 86.9 (SD = 6.7).

The descriptive statistics indicate substantial gains in both domains, with numeracy showing a slightly higher percentage increase than literacy. To examine whether these observed improvements were statistically significant, paired-sample t-tests were subsequently conducted.

Table 2. Paired-Sample t-Test Results for Literacy and Numeracy

Domain	Mean Pre-test	Mean Post-test	t(34)	p-value	Effect Size (Cohen's *d*)	Interpretation
Literacy	68.2	87.5	12.48	< .001	2.10	Very large effect
Numeracy	66.2	86.9	13.02	< .001	2.20	Very large effect

Both tests yielded highly significant results ($p < .001$), confirming that students' literacy and numeracy scores improved significantly after using the SmartBook. The effect sizes (d = 2.10 and 2.20) are considered very large (Cohen, 1988), indicating robust educational impact.

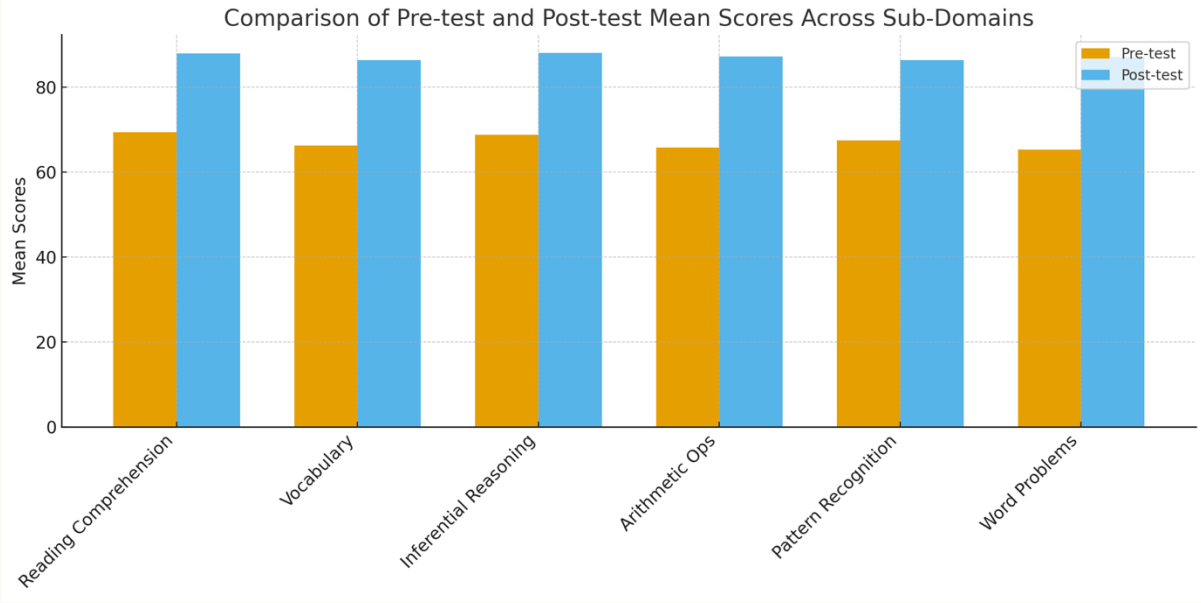

Figure 1. Comparison of pre-test and post-test mean gains across sub-domains of literacy and numeracy

Overall, the largest improvement occurred in numerical problem-solving (+21.8) and vocabulary understanding (+20.1). These findings suggest that multimodal AR input and contextual language scaffolds effectively supported both conceptual and lexical development (Ibáñez & Delgado-Kloos, 2018).

Table 3. Distribution of students' literacy and numeracy achievement categories (Low = <70, Moderate = 70–84, High = ≥85) before and after the intervention.

Category	Literacy Pre	Literacy Post	Numeracy Pre	Numeracy Post
Low (<70)	46%	6%	49%	3%
Moderate (70–84)	43%	31%	40%	29%
High (≥85)	11%	63%	11%	68%

The percentage of students in the high-achievement category increased substantially in both domains. Literacy showed an increase of 52 percent, while numeracy increased by 57 percent. In contrast, the proportion of students in the low-achievement category declined markedly. This categorical shift indicates a substantial redistribution of students' achievement levels following the implementation of SmartBook-based learning.

In addition to the quantitative outcomes, classroom observations conducted during the implementation of SmartBook LKPD DigiLitNum provided complementary evidence regarding students' learning behaviors. During SmartBook-based lessons, teachers consistently reported higher levels of enthusiasm, participation, and task focus. Students interacted actively with the AR components, asked clarification questions related to the learning content, and showed greater persistence when completing literacy and numeracy activities.

Table 4. Observed Student Engagement Indicators During SmartBook Lessons

Engagement Indicator	Observed Behaviors	Teacher Notes
Enthusiasm	Students reacted positively to AR animations, showed excitement when scanning pages	Increased verbal responses ("let me try," "what happens next?")
Participation	More students volunteered to answer questions, read aloud, or demonstrate tasks	Participation broadened beyond the same few students
Task Focus	Students spent longer continuous time completing literacy and numeracy tasks	Fewer off-task behaviors recorded during AR activities
Peer Collaboration	Students helped each other operate the AR app and interpret visuals	Increased peer discussion during problem-solving
Curiosity	Students frequently asked "why" and "how" questions related to content	Clear increase in spontaneous questions to the teacher

Overall, the observational data align with the quantitative findings by documenting consistent patterns of active participation and sustained engagement during SmartBook-based instruction. These observations conclude the Results section by providing behavioral context for the measured improvements in literacy and numeracy performance.

4. Discussion

This study examined the effectiveness of SmartBook LKPD DigiLitNum, an AR-supported interactive workbook, in enhancing Grade 3 students' literacy and numeracy performance. The findings demonstrate significant improvements in both domains, which is consistent with recent empirical studies indicating that AR-based learning environments positively affect literacy and numeracy outcomes in elementary education contexts (Sagita et al., 2025; Pasaribu et al., 2024; Sundari et al., 2025). Notably, the descriptive results revealed that numeracy showed a slightly higher percentage increase than literacy. This pattern suggests that AR-based visualization may have provided benefits for contextualizing mathematical concepts, especially those involving abstract numerical relationships.

The notable gains in literacy and numeracy suggest that the multimodal and context-rich design of the SmartBook facilitated deeper comprehension and conceptual transfer. In line with the Cognitive Theory of Multimedia Learning, students processed information through coordinated verbal and visual channels, which supported dual coding and more robust schema construction (Mayer, 2020). This dual processing likely reduced extraneous

cognitive load and enhanced meaningful learning, thereby improving students' understanding of both linguistic and numerical concepts.

A distinctive contribution of this study lies in the integration of Augmented Reality with Learning Analytics within a single instructional resource. This dual approach enabled immersive visualization for students while providing teachers with real-time data to monitor learning progress and adjust instruction accordingly. Such integration aligns with previous findings that AR-supported learning combined with data-informed instruction can strengthen active learning and formative feedback practices in classrooms (Ibáñez & Delgado-Kloos, 2018; Ifenthaler & Yau, 2020).

In literacy learning, the findings corroborate recent Indonesian studies showing that AR-enhanced reading materials improve vocabulary mastery, reading comprehension, and learner motivation among primary school students (Kurniasih et al., 2022; Sagita et al., 2025). The observed improvements suggest that AR-supported visualizations and contextual narratives encouraged students to infer meaning, engage more deeply with texts, and develop positive attitudes toward reading. These results reinforce the view that AR enhances both cognitive and affective dimensions of literacy learning.

From a theoretical perspective, the learning gains can be explained through constructivist and embodied learning frameworks. Constructivist theory emphasizes that learners actively construct knowledge through interaction and reflection, while embodied cognition highlights the role of sensory and motor experiences in understanding abstract concepts (Furió et al., 2015). The SmartBook design encouraged students to interact with AR elements by scanning codes, manipulating virtual objects, and linking digital representations to real-world contexts. This interactive process was particularly beneficial in numeracy learning, where abstract numerical relationships were visualized and explored concretely.

Motivation and engagement also played a crucial role in mediating the observed learning outcomes. AR-based activities created interactive and visually appealing learning experiences that sustained students' attention and curiosity. Consistent with recent findings, higher levels of engagement were associated with improved academic performance, indicating that motivation acts as an important pathway through which AR influences learning outcomes (Korosidou, 2024; Sundari et al., 2025). In numeracy tasks, AR simulations enabled students to experiment with problem-solving strategies, supporting exploratory learning and deeper conceptual understanding.

Beyond instructional outcomes, this study highlights the value of community-based educational innovation. Implemented as part of a university–school partnership, the SmartBook initiative reflects the principles of service-learning by linking academic expertise with local educational needs. Collaborative involvement of university lecturers, student assistants, and elementary school teachers contributed to the sustainability of the intervention and strengthened teacher capacity to integrate digital innovation into classroom practice (Bringle & Hatcher, 1996).

Despite these positive outcomes, several limitations should be acknowledged. The use of a one-group pre-test–post-test design without a control group limits causal inference. The relatively small sample size and single-school context may also constrain the generalizability of the findings. In addition, qualitative data capturing students' perceptions and learning experiences were not systematically collected. Future studies are encouraged to employ experimental or quasi-experimental designs, involve multiple schools, and adopt mixed-methods approaches to provide a more comprehensive understanding of AR-based learning interventions.

In terms of pedagogical implications, SmartBook LKPD DigiLitNum aligns well with the principles of Kurikulum Merdeka by supporting inquiry-based and differentiated instruction. The integration of AR facilitates concrete visualization of abstract concepts, while offline-accessible features and low-spec device compatibility help address issues of digital inequality commonly encountered in Indonesian schools (Halim et al., 2024; Rosita et al., 2025). The findings also reinforce the view that literacy and numeracy are interconnected competencies that can be developed simultaneously through integrated, technology-enhanced learning materials.

Overall, this study contributes an empirically grounded and contextually relevant model for advancing literacy and numeracy education in Indonesia. By integrating AR into curriculum-aligned printed workbooks and embedding Learning Analytics for instructional support, SmartBook LKPD DigiLitNum offers a scalable and student-centered approach that bridges digital innovation with practical classroom implementation.

5. Conclusion

This study demonstrated that the implementation of SmartBook LKPD DigiLitNum effectively improved third-grade students' literacy and numeracy performance. Substantial learning gains were observed in both domains, accompanied by a clear shift in students' achievement levels from predominantly low and moderate categories to high achievement. In addition to improved academic outcomes, classroom observations indicated increased student engagement, participation, and persistence during SmartBook-based learning activities.

From an educational perspective, the findings highlight the value of integrating Augmented Reality into curriculum-aligned printed learning materials to support multimodal and contextualized learning experiences. The study also reinforces the interrelated nature of literacy and numeracy as foundational competencies that can be developed simultaneously through integrated and technology-enhanced instructional approaches. These results suggest that AR-supported SmartBooks can serve as effective tools for fostering meaningful learning in elementary classrooms.

In practical terms, this research provides empirical evidence supporting the use of SmartBook LKPD DigiLitNum as an innovative learning model within Indonesian elementary education. Teachers may utilize AR-based SmartBooks to facilitate visual and interactive instruction, while Learning Analytics can support ongoing assessment and instructional monitoring. Future research is encouraged to expand implementation across multiple schools and examine long-term learning retention to further assess scalability and sustainability.

6. Acknowledgement

This article is derived from a community service program funded by the Direktorat Penelitian dan Pengabdian kepada Masyarakat (DPPM) Direktorat Jenderal Pendidikan Tinggi, Riset, dan Teknologi (DIKTI), Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia, contract number 033/SP/II.3.AU/LPPM/PM/2025. The authors express their sincere appreciation to DPPM DIKTI for the financial support that made the implementation of this program and the completion of this publication possible.

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