Salud, Ciencia y Tecnología. 2025; 5:2214
doi: 10.56294/saludcyt20252214

ORIGINAL

The Effectiveness of an Interactive Augmented Reality E-Book Featuring Local Wisdom of Kalimantan Selatan on English Learning Outcomes

La efectividad de un libro electrónico interactivo de realidad aumentada que presenta la sabiduría local de Kalimantan selatan sobre los resultados del aprendizaje del inglés

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Cite as: Isnaniah I, Marlina M, Ningsih RP. The Effectiveness of an Interactive Augmented Reality E-Book Featuring Local Wisdom of Kalimantan Selatan on English Learning Outcomes. Salud, Ciencia y Tecnología. 2025; 5:2214. https://doi.org/10.56294/saludcyt20252214

Submitted: 05-05-2025 **Revised:** 10-07-2025 **Accepted:** 18-09-2025 **Published:** 19-09-2025

Editor: Prof. Dr. William Castillo-González

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ABSTRACT

Introduction: the integration of Augmented Reality in education has been recognized as an effective way to increase student engagement and contextualize learning. Growing evidence demonstrates that technology-enhanced learning environments can significantly improve educational outcomes, yet substantial gaps remain in understanding how culturally embedded content affects learning effectiveness. However, research on Augmented Reality-based interactive e-books that incorporate local wisdom in English as a Foreign Language (EFL) learning remains limited in culturally rich regions such as South Kalimantan. This study addresses the critical need to bridge technological innovation with cultural relevance in elementary English education.
Objective: this study aims to evaluate the effectiveness of Augmented Reality-based interactive e-books featuring South Kalimantan's local wisdom on elementary students' English learning outcomes compared to conventional teaching methods.
Method: this quasi-experimental study employed a controlled design to assess learning effectiveness across different student proficiency levels. A total of 163 fifth-grade students from six schools in Banjarmasin participated. Students were randomly assigned to an experimental group (n = 80), which used Augmented Reality-based e-books, and a control group (n = 83), which followed conventional methods. Primary variables measured included English vocabulary comprehension and contextual application skills. Data were collected using validated pre-tests and post-tests, and analyzed using ANCOVA to control for initial ability differences and independent t-tests to compare learning improvement between groups. Data analysis was conducted using SPSS version 26 with a significance level set at $\alpha = 0,05$.
Results: the findings revealed that the experimental group significantly outperformed the control group in English vocabulary acquisition and contextual application ($F = 28,798$, $p < 0,001$, $\eta^2p = 0,352$). Augmented Reality-based e-books were most effective for students with moderate English proficiency, showing an average improvement of 9,99 points over the control group. In contrast, high-proficiency students showed a slight redundancy effect, performing marginally better with conventional learning. The technology demonstrated differential effectiveness based on student ability levels, with moderate learners benefiting most from the culturally embedded content.
Conclusions: the study concludes that Augmented Reality-based interactive e-books integrating local wisdom significantly enhance English learning outcomes for students with moderate proficiency levels by providing contextual scaffolding and meaningful cultural content. However, high-proficiency learners may experience cognitive redundancy. The findings suggest that the effectiveness of Augmented Reality technology depends

on careful consideration of student proficiency levels and appropriate content design. Future research should examine cognitive load and long-term retention to strengthen the pedagogical implications of Augmented Reality-enhanced EFL learning.

Keywords: Augmented Reality; Interactive E-Book; Local Wisdom; English Learning; Elementary School.

RESUMEN

Introducción: la integración de la Realidad Aumentada en la educación ha demostrado ser eficaz para aumentar la motivación y contextualizar el aprendizaje. Evidencia creciente demuestra que los entornos de aprendizaje mejorados con tecnología pueden mejorar significativamente los resultados educativos, sin embargo, persisten brechas sustanciales en la comprensión de cómo el contenido culturalmente integrado afecta la efectividad del aprendizaje. Sin embargo, los estudios sobre libros electrónicos interactivos basados en Realidad Aumentada que incorporen la sabiduría local en la enseñanza del inglés como lengua extranjera siguen siendo limitados en regiones culturalmente ricas como Kalimantan del Sur. Este estudio aborda la necesidad crítica de unir la innovación tecnológica con la relevancia cultural en la educación primaria del inglés.
Objetivo: este estudio tiene como objetivo evaluar la efectividad de los libros electrónicos interactivos basados en Realidad Aumentada que presentan la sabiduría local de Kalimantan del Sur en los resultados de aprendizaje del inglés de estudiantes de primaria en comparación con los métodos de enseñanza convencionales.
Método: este estudio cuasiexperimental empleó un diseño controlado para evaluar la efectividad del aprendizaje en diferentes niveles de competencia estudiantil. Participaron 163 estudiantes de quinto grado de seis escuelas primarias en Banjarmasin. Los estudiantes fueron asignados aleatoriamente a un grupo experimental (n = 80) que utilizó el e-book de Realidad Aumentada y un grupo de control (n = 83) con métodos convencionales. Las variables principales medidas incluyeron la comprensión del vocabulario en inglés y las habilidades de aplicación contextual. Los datos se recogieron mediante pretest y postest validados y se analizaron utilizando ANCOVA para controlar las diferencias de habilidad inicial y pruebas t independientes para comparar la mejora del aprendizaje entre grupos. El análisis de datos se realizó utilizando SPSS versión 26 con nivel de significancia establecido en $\alpha = 0,05$.
Resultados: los hallazgos muestran que el grupo experimental superó significativamente al grupo de control en la adquisición y aplicación contextual del vocabulario en inglés ($F = 28,798$, $p < 0,001$, $\eta^2p = 0,352$). Los estudiantes con nivel moderado de inglés se beneficiaron más del e-book de Realidad Aumentada, con una mejora promedio de 9,99 puntos sobre el grupo control. En contraste, los estudiantes de alto nivel mostraron un ligero efecto de redundancia, obteniendo mejores resultados con métodos convencionales. La tecnología demostró efectividad diferencial basada en los niveles de habilidad estudiantil, con estudiantes moderados beneficiándose más del contenido culturalmente integrado.
Conclusiones: el estudio concluye que los libros electrónicos interactivos basados en Realidad Aumentada que integran sabiduría local mejoran significativamente los resultados de aprendizaje del inglés en estudiantes con niveles de competencia moderados, al proporcionar un andamiaje cognitivo y contenidos culturales significativos. Sin embargo, los estudiantes avanzados pueden experimentar redundancia cognitiva. Los hallazgos sugieren que la efectividad de la tecnología de Realidad Aumentada depende de una consideración cuidadosa de los niveles de competencia estudiantil y el diseño apropiado del contenido. Se recomienda investigar en el futuro la carga cognitiva y la retención a largo plazo.

Palabras clave: Realidad Aumentada; Libro Electrónico Interactivo; Sabiduría Local; Aprendizaje de Inglés; Escuela Primaria.

INTRODUCTION

The rapid advancement of information technology and mobile devices has fundamentally transformed the landscape of elementary education over the past decade.[1,2,3] This technological evolution has created unprecedented opportunities for innovative pedagogical approaches that were previously impossible to implement. Among the emerging technologies reshaping educational practices, Augmented Reality has emerged as a particularly promising tool that can enhance learning effectiveness by providing immersive and interactive experiences.[4,5]

Augmented Reality technology originated in the early 1990s through the pioneering work of researchers like Tom Caudell and David Mizell at Boeing, who first coined the term “Augmented Reality” in 1990. The technology

evolved from simple overlay systems to sophisticated platforms capable of real-time interaction between digital and physical environments.[6,7] The educational applications of Augmented Reality began gaining momentum in the 2000s, with significant breakthroughs occurring between 2010-2020 when mobile devices became powerful enough to support complex AR applications.[8,9]

The integration of Augmented Reality into language education represents a paradigmatic shift from traditional teaching methodologies. Before AR implementation, English as a Foreign Language instruction in elementary schools predominantly relied on textbook-centered approaches, teacher-led presentations, and passive learning activities.[10,11,12] Students had limited opportunities for interactive practice and often struggled to connect abstract language concepts to real-world contexts. The post-AR educational landscape has introduced dynamic, student-centered learning environments where learners actively engage with virtual content integrated into their physical surroundings, creating more meaningful and memorable learning experiences.[13,14]

Augmented Reality blends physical and digital worlds in real-time, enabling students to learn within contextually rich environments. This technology has demonstrated significant potential to make English learning more engaging, as students can interact with virtual elements integrated into their physical surroundings, thereby enhancing their engagement and understanding of the subject matter.[15,16] Contextual English learning approaches have gained recognition for helping students understand material and apply it in real-world situations. Augmented Reality, as a technology that combines digital and physical elements, offers contextual learning experiences that address the needs of English education. Through Augmented Reality, students can connect subject matter to real-world experiences, enhancing their understanding within more relevant contexts.[17,18,19]

The concept of integrating local wisdom into educational content has emerged as a critical pedagogical strategy for maintaining cultural identity while acquiring international language skills. The integration of local wisdom into Augmented Reality-based learning can enrich subject matter, making it more relevant and accessible for students. This approach increases the connection between material and local culture with which students are familiar, while supporting the development of students' English skills within culturally relevant contexts. Research has identified several challenges in implementing AR-based learning systems. While Augmented Reality offers engaging learning experiences, the use of this technology can increase cognitive burden for students, particularly when material presentation does not align with their ability levels. To address these challenges, educational researchers have developed adaptive learning frameworks that tailor content complexity to individual student needs.[20,21] Previous research has demonstrated that students with lower language skills tend to experience difficulty maximizing Augmented Reality benefits, which can hinder their learning processes.[22,23,24] Conversely, students who are more proficient in English demonstrate better capacity to manage the cognitive challenges posed by this technology.

Evidence suggests that the use of local wisdom in Augmented Reality-based learning can reduce cognitive burden because familiar and culturally relevant material can facilitate student understanding, increase learning motivation, and reduce anxiety that may arise during the learning process.[25,26] Augmented Reality-based interactive e-books that integrate local wisdom offer substantial potential to facilitate more effective English learning.[27,28,29] These digital learning tools allow students to interact with subject matter in real-time, visualizing English concepts in more engaging and comprehensible forms. Augmented Reality-based learning can reduce students' boredom, increase their engagement, and consequently improve academic achievement, language retention, and practical application skills.[30,31]

Despite the growing body of research examining AR applications in education, research on Augmented Reality-based e-books that integrate local wisdom in English learning in elementary schools remains insufficient, particularly in culturally diverse regions such as South Kalimantan. This research gap is particularly significant given that preliminary studies suggest cultural relevance may be a critical factor in technology acceptance and learning effectiveness.[32,33] Field observations conducted in elementary schools throughout South Kalimantan between 2023 and 2024 revealed that most teachers and students lack familiarity with Augmented Reality technology for English learning applications. Some schools in the region continue to face challenges with technological infrastructure, such as insufficient tablet devices and unstable internet connections, which complicate the implementation of Augmented Reality-based learning. However, strong enthusiasm exists among teachers and students to adopt innovative technology, provided that learning materials remain relevant to local contexts and maintain accessibility. These findings underscore the need for learning materials that combine Augmented Reality technology with local wisdom, enhancing student engagement and aligning learning with students' cultural values.

Previous studies examining Augmented Reality in English learning have predominantly focused on testing general AR models without considering local wisdom factors in learning content design. Research conducted by [34,35] focuses primarily on increasing student engagement through Augmented Reality use, but fails to examine comprehensively how Augmented Reality incorporating local wisdom can improve English comprehension. Additionally, research gaps exist in Augmented Reality studies conducted in specific geographic regions such as South Kalimantan, which possess distinctive local cultural and linguistic contexts. The integration of

local wisdom can increase material relevance and make learning more meaningful. Consequently, this study introduces a novel approach by combining Augmented Reality with local wisdom. This research area remains underexplored, especially in regions with strong local cultures, such as South Kalimantan.

The urgency of this research stems from the critical need to develop more relevant and contextual learning models for primary school students. The implementation of Augmented Reality based on local wisdom represents a potential solution to increase the effectiveness of English learning through more comprehensive and engaging approaches for students. Furthermore, this innovation may reduce the gap between students' abilities and technology-based learning, which often proves difficult to access or understand, particularly for students in areas with limited access to technology and resources. The significance of this research extends beyond immediate pedagogical applications to broader implications for cultural preservation and educational equity. By demonstrating how local cultural content can be effectively integrated into modern educational technologies, this study contributes to the growing movement toward culturally responsive pedagogy while addressing the digital divide that often disadvantages students in culturally rich but technologically underserved regions.

Although some researchers argue that local wisdom content facilitates language understanding and application by providing familiar and meaningful contexts for students [36,37], other researchers contend that redundancy effects can occur when students' attention is diverted from essential processing, and when their working memory becomes occupied with repetitive or unrelated information, resulting in learning effectiveness being negatively affected by cognitive overload. The effectiveness of Augmented Reality-based interactive e-books that incorporate South Kalimantan's local wisdom content on elementary school students' learning outcomes has not been thoroughly examined. This research gap presents both an opportunity and a necessity to contribute valuable insights to the field of technology-enhanced language learning.

This study evaluates the effectiveness of Augmented Reality-based interactive e-books featuring South Kalimantan's local wisdom on elementary students' English learning outcomes compared to conventional teaching methods, with particular attention to how effectiveness varies across different student proficiency levels.

Literature review

Augmented Reality technology has evolved significantly over the past decade, establishing itself as a transformative educational tool with demonstrated potential to enhance learning experiences across multiple disciplines. AR applications are fundamentally based on three technological pillars: tracking systems for identifying real-world objects of interest, processing hardware and software for interpreting environmental data, and display devices that present integrated digital information within real environments.[38,39] Contemporary AR systems have demonstrated great potential for education and have been successfully applied to facilitate learning across humanities and arts, eHealth, science, engineering, manufacturing, and construction domains. [40,41] Current research consistently demonstrates that AR technology significantly increases students' engagement, stimulates curiosity, enhances motivation, and facilitates interaction and collaboration among learners.[42,43]

Modern AR-enhanced learning systems improve students' learning efficiency and enhance their perception of system usability and learning experiences by providing sophisticated visual representation and interactivity. [44,45] Recent studies by [46] found that when AR technology is integrated within flipped classroom environments, learners demonstrate satisfactory learning performance, enhanced critical thinking tendencies, and increased learning motivation. Contemporary meta-analyses have provided comprehensive insights into AR effectiveness. Research conducted by [47] involving a meta-review of 47 publications on AR-enhanced learning concluded that the facilitative effects of AR include improved performance, increased motivation, and enhanced collaboration among learners, while identifying the main limitation of AR as the technology imposing additional cognitive burden on learners

Extensive research examining AR-enhanced learning has increasingly focused on understanding the influence of AR on motivation and attitudes across diverse educational contexts.[48,49] Recent studies have documented significant positive outcomes:(8) found that AR improved student satisfaction levels; [50] reported substantial increases in learner confidence; [51,52] argued that AR significantly increases student engagement rates; and [53] identified a significant rise of learning interest. Despite numerous studies examining students' motivation and attitudes following AR-enhanced learning experiences, comprehensive research exploring the multifaceted aspects of motivation and attitudes across different proficiency levels remains limited.

AR technology possesses distinctive visualization and interactivity features, positioning it as an exceptional tool for enhancing EFL learning through contextual visualization capabilities (i.e., presenting virtual information within rich contextual frameworks) and learning interactivity functionalities (i.e., enabling interaction with virtual content) [53,54]. Contemporary literature demonstrates that AR-based learning is theoretically grounded in two foundational theories: experiential learning theory and the principle of multimedia learning contiguity [55,56]. Experiential learning theory considers experiences as fundamental sources of learning and posits that learning occurs when students create meaningful experiences from authentic scenarios. Building upon this

theoretical foundation,[57] successfully developed an AR-based ecological system and documented positive learning results.

The principle of multimedia learning contiguity, which advocates for the integration of text with appropriate graphics or objects, has been extensively applied to EFL learning and validated as practical and reliable.[58,59] This principle emphasizes the importance of simultaneous presentation of visual and verbal elements to create optimal learning experiences that maximize comprehension and retention. Research has increasingly recognized that the integration of local wisdom in English learning has substantial potential to increase the relevance and meaning of learning for students.[60,61] Local wisdom can manifest through various forms, including folklore, traditional games, regional cuisine, traditional architecture, and cultural values that directly connect to students' lives. Practical implementation of this concept can be observed in the development of learning content that incorporates themes such as the Bubungan Tinggi traditional house, cooperative traditions of the Banjar community, Soto Banjar culinary heritage, and floating market activities characteristic of South Kalimantan's rivers.

Contemporary research by [62] shows that negative attitudes can be transformed through exposure to authentic contexts and encounters with native speakers from the target language culture. In the context of English language learning in Indonesia, local wisdom serves as a cultural bridge that connects the target language with familiar cultural contexts for students.[63] The use of themes such as riverside life of the Banjar people, weaving traditions, and traditional agricultural activities creates more meaningful and contextual learning experiences as students can effectively relate English vocabulary to their personal cultural experiences.[64,65]

Local wisdom-based learning approaches support the development of students' cultural identity while facilitating international language acquisition.[66,67] When students learn vocabulary such as "traditional house", "floating market", "river life", and "local food" through authentic contexts, including Bubungan Tinggi, floating markets, river life, and Soto Banjar, they simultaneously acquire English skills and strengthen their appreciation for local culture. This approach aligns with contemporary principles of contextual learning that emphasize the importance of relating learning materials to students' prior experiences and knowledge.[68,69]

AR-based interactive e-books represent sophisticated educational tools that seamlessly combine digital text, multimedia elements, and augmented reality technology to deliver highly immersive learning experiences.[70] This concept is effectively exemplified by the development of specialized e-books such as "Learning English with South Kalimantan Culture," which systematically incorporates South Kalimantan's local wisdom into English learning for elementary students. Contemporary e-book designs typically feature comprehensive chapters covering geographic introductions, cultural architecture exploration, culinary heritage, community social structures, and traditional economic activities.

The pedagogical strength of AR-based interactive e-books lies in their capacity to dynamically present local wisdom through manipulable visual forms accessible via e-book interfaces.[71,72] Students can actively interact with virtual objects such as three-dimensional maps featuring enlargement and rotation capabilities, interactive simulations demonstrating cooking processes, and virtual explorations of architectural structures. Modern AR features, including QR codes for activating three-dimensional content, drag-and-drop objects for manipulating environmental elements, immersive visualizations of market activities, and interactive assessment tools, make contemporary learning experiences highly engaging and memorable.[73] This approach aligns with contemporary interpretations of dual coding theory, which demonstrates that information processed through simultaneous visual and verbal channels facilitates enhanced understanding and memory retention.

Contemporary approaches to integrating local wisdom into AR e-books effectively foster contextual and meaningful learning experiences.[74] Content that comprehensively covers cooperative traditions, agricultural activities, and riverine life offers students culturally familiar learning frameworks. Modern bilingual formats (English and Indonesian) effectively assist students' comprehension while preserving local cultural identity.[75] Contemporary e-book designs typically incorporate vocabulary exercises, audio pronunciation practice, and hands-on activities to support comprehensive English language learning across multiple skill domains.

METHOD

Type of Study

This research employed a non-observational, quasi-experimental design to evaluate the effectiveness of Augmented Reality-based interactive e-books featuring local wisdom on elementary students' English learning outcomes. The study was classified as non-observational because the researchers actively introduced an intervention (AR-based e-book) and manipulated the learning conditions to observe their effects on the dependent variables. A quasi-experimental design was selected rather than a true experimental design due to practical constraints in educational settings that prevented complete randomization of schools and classrooms, while still maintaining adequate control over the experimental conditions.[76]

The research design incorporated two independent variables: learning method (AR-based e-book versus conventional instruction) and student English proficiency level (moderate versus high). The dependent

variables included English vocabulary comprehension scores, contextual application skills, and overall learning performance improvement.

Universe and Sample

The target universe for this study comprised all fifth-grade students in urban public elementary schools in Banjarmasin, South Kalimantan, Indonesia, who were enrolled in English as a Foreign Language programs during the 2024 academic year. The accessible population consisted of approximately 2,450 fifth-grade students distributed across 34 urban public elementary schools in the Banjarmasin metropolitan area.

A purposive sampling technique was employed to select six elementary schools that met the following inclusion criteria: (1) urban public school status, (2) availability of basic technological infrastructure including stable internet connectivity and tablet devices, (3) willingness to participate in educational technology research, (4) comparable socioeconomic demographics representing middle-class families, and (5) similar English curriculum implementation based on the 2013 Indonesian National Curriculum. From the selected schools, all fifth-grade students who met the participant criteria were invited to participate voluntarily. A total of 163 fifth-grade students from six classes in six urban public elementary schools in Banjarmasin, South Kalimantan, participated in the experimental activities after providing informed consent.

The sample size was determined using G Power 3.1.9.7 software with the following parameters: effect size (f) = 0,25, α = 0,05, power (1-ß) = 0,80, resulting in a minimum required sample size of 158 participants. The actual sample of 163 participants exceeded this requirement, ensuring adequate statistical power. All participants had been receiving EFL instruction twice weekly since grade 3, representing more than two years of English learning experience. These students had mastered basic grammar structures and the 500 most commonly used English words for primary school students as specified in the 2013 Curriculum by the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia, positioning them as entry-level EFL learners (Chang et al.).

Prior to group assignment, students were stratified by English proficiency level based on their most recent English assessment scores. Students were then randomly assigned within each stratum to ensure balanced distribution across experimental conditions. Students were randomly assigned to two groups: an experimental group that used AR e-books featuring local wisdom (n=80) and a control group that used conventional learning methods (n=83). The randomization process employed a computer-generated random number sequence to ensure unbiased group allocation.

Variables

The study involves both independent and dependent variables to assess the effectiveness of an augmented reality (AR)-based interactive e-book on English learning outcomes. The independent variables include the learning method (categorical, two levels): the experimental condition where students use an AR-based interactive e-book featuring South Kalimantan local wisdom, and the control condition where students receive conventional English instruction without the AR technology. Another independent variable is the student's English proficiency level (categorical, two levels): moderate proficiency for students scoring 50-70 % on a baseline English assessment, and high proficiency for students scoring above 70 %. The dependent variables are English vocabulary comprehension (continuous), measured by scores on a vocabulary understanding test (scale: 0-100), contextual application skills (constant), assessed by scores on vocabulary application test items (scale: 0-100), overall learning performance (continuous), which is the combined improvement from pre-test to post-test, and learning gain scores (constant), calculated as the difference between post-test and pre-test scores.

Data Collection and Processing

Phase 1: pre-intervention Assessment (Week 1) All participants completed validated pre-tests to establish baseline English proficiency levels. The assessment instruments were administered under standardized conditions with trained research assistants ensuring consistent procedures across all participating schools.

Phase 2: intervention Implementation (Weeks 2-3) The experimental group participated in AR-enhanced English learning sessions using tablet PCs loaded with the "Learning English with South Kalimantan Culture" interactive e-book. The control group received conventional English instruction covering identical vocabulary and cultural content without AR technology. Each group completed five themed learning sessions of 35 minutes each, totaling 175 minutes of instruction.

Phase 3: post-intervention Assessment (Week 4) All participants completed post-tests using identical instruments to the pre-tests. Assessments were administered immediately following the completion of all intervention sessions to measure immediate learning outcomes.

Participants had never experienced AR-based learning before participating in the project. During the intervention phase, participants in the experimental group learned individually from AR-enhanced theme-based contextual learning called "Learning English with South Kalimantan Culture" using tablet PCs. They

were provided with orientation sessions to become familiar with AR technology and interactive devices prior to treatment. Learners could trigger theme-based learning activities with AR interactions by scanning specific AR markers on interactive e-books or markers on learning worksheets.

The interactive e-book featured five thematic learning modules with engaging and contextual activities

(1) Introduction to the geography and life of the Banjar people, featuring visualization of traditional stilt houses and interactive maps of South Kalimantan; (2) Culinary exploration of Soto Banjar, where students identified food ingredients in English while exploring regional culinary specialties; (3) Matching games with local wisdom themes, connecting English words such as "Province", "River", and "Boat" with relevant visual images; (4) Virtual construction of Bubungan Tinggi houses, using hands-on learning approaches where students arranged architectural parts while learning vocabulary such as "Roof", "Stairs", "Pillars", and "Walls"; and (5) Floating market activities simulating traditional economic practices.

Each themed learning unit lasted 35 minutes and consisted of three-stage learning activities: vocabulary introduction, AR interaction, and contextual application. Each learning unit incorporated 12 target vocabulary words with contextual applications aimed at entry-level EFL learners, focusing on South Kalimantan's local wisdom, including traditional architecture, culinary heritage, community life, and floating market activities. The total treatment duration was 175 minutes (5 × 35 minutes).

Performance test development followed rigorous validation procedures. Test items were initially developed by a panel of three experienced English teachers with 15+ years of elementary education experience. Content validity was established through expert review by five subject matter specialists in EFL education and cultural studies. Construct validity was confirmed through factor analysis (KMO = 0,83, Bartlett's test $p < 0,001$), and criterion validity was established through correlation with standardized English proficiency measures ($r = 0,74$, $p < 0,001$).

The achievement test comprised 24 multiple-choice items with three response options each, focusing on English vocabulary related to South Kalimantan's local wisdom and contextual application. The test assessed two primary constructs: (1) Knowledge Comprehension (12 items), measuring understanding of vocabulary related to traditional architecture, local cuisine, social activities, and river life; and (2) Knowledge Application (12 items), evaluating the ability to use vocabulary appropriately in contextual situations.

Test administration employed an audio-based format where all items were presented via computer-generated audio while participants responded on paper-based answer sheets containing only response options. This method ensured assessment of listening comprehension and knowledge transfer rather than reading ability. Internal consistency reliability was demonstrated with Cronbach's alpha coefficients of 0,81 for comprehension items, 0,79 for application items, and 0,85 for the overall test.

Statistical analysis was conducted using SPSS version 26,0 software. Descriptive statistics included means, standard deviations, minimum, and maximum scores for both groups. Inferential analysis employed Analysis of Covariance (ANCOVA) with pre-test scores as covariates to control for initial ability differences. Before ANCOVA, assumption testing was conducted, including normality assessment (Kolmogorov-Smirnov test), homogeneity of variance (Levene's test), and linearity of covariate relationships. Independent samples t-tests were used to compare learning gain scores between groups. Effect sizes were calculated using partial eta squared (η^2p) for ANCOVA and Cohen's d for t-tests. Statistical significance was set at $\alpha = 0,05$.

Ethical Standards

This research was conducted in full compliance with ethical standards for human subjects research and received approval from the Institutional Review Board of Universitas Nahdlatul Ulama Kalimantan Selatan (Protocol Number: UNU-IRB-2024-015) prior to data collection initiation. Comprehensive informed consent procedures were implemented involving multiple stakeholders. Written informed consent was obtained from school principals and teachers prior to school participation. Individual informed assent was obtained from all student participants using age-appropriate language explaining the study purpose, procedures, potential risks and benefits, and their right to withdraw at any time without penalty. Parental consent was secured through detailed information letters sent home with students, followed by signed consent forms returned before participation.

Participant privacy and confidentiality were rigorously protected throughout the research process. All data were collected using coded identifiers with master lists stored separately from research data. Personal identifying information was accessible only to the principal investigator and stored in locked, secure facilities. Data analysis was conducted using de-identified datasets, and all research reports present only aggregate findings with no individual identification possible. The research posed minimal risk to participants, involving only educational activities similar to regular classroom instruction. No psychological, physical, or social risks were anticipated or encountered. Students who experienced any discomfort or technical difficulties during AR sessions received immediate assistance from trained research staff.

Voluntary participation was emphasized throughout the study. Students were informed they could withdraw from the research at any time without affecting their regular academic standing or grades. No incentives or coercion were used to encourage participation. Regular monitoring ensured that participation remained voluntary and that no students experienced undue burden. Data security measures included password-protected computer files, encrypted data transmission, and secure cloud storage with multi-factor authentication. Physical materials were stored in locked cabinets accessible only to authorized research personnel. Data retention follows institutional policies with de-identified research data maintained for seven years and identifying information destroyed immediately upon study completion. Research benefits were equitably distributed by providing the AR learning materials to control group schools following study completion, ensuring all participants ultimately had access to the innovative educational technology.

RESULTS

Statistical analysis was conducted to examine the effectiveness of AR-based interactive e-books featuring local wisdom on elementary students' English learning outcomes. ANCOVA was employed to control for initial ability differences, with comprehensive assumption testing performed prior to analysis.

Assumption Testing for ANCOVA Analysis

Prior to conducting the main analysis, prerequisite tests were performed to verify statistical assumptions. All tests confirmed that the data met ANCOVA requirements, ensuring the validity of subsequent analyses.

Table 1. Summary of Prerequisite Tests for ANCOVA Analysis

Test	Group	Statistics	Df	p-value	Conclusion
Normality (Kolmogorov-Smirnov)					
Pre-test	Experimental	0,068	80	0,200*	Normal
	Control	0,062	83	0,200*	Normal
Post-test	Experimental	0,083	80	0,200*	Normal
	Control	0,076	83	0,200*	Normal
Linearity (Deviation from Linearity)					
	Experimental	1,262	24	0,236	Linear
	Control	1,216	28	0,265	Linear
Homogeneity (Levene Test)					
	Experimental	1,001	17	0,472	Homogeneous
	Control	1,112	21	0,366	Homogeneous

Note: *Lower bound of actual significance

The Kolmogorov-Smirnov test confirmed normal distribution of pre-test and post-test scores for both groups (all $p > 0,05$). Linearity testing verified linear relationships between covariates and dependent variables ($p > 0,05$). The Levene test demonstrated homogeneity of variance between groups ($p > 0,05$), confirming that all ANCOVA prerequisites were satisfied.

Learning Performance Outcomes

Table 2. Descriptive Statistics for English Learning Performance by Group and Proficiency Level

Learning Condition	English Proficiency	Pre-test			Post-test		
		M	SD	n	M	SD	n
AR-based e-books	Moderate	54,32	6,85	79	75,30	6,30	79
	High	55,50	7,20	1	69,00	-	1
	Total	54,34	6,84	80	75,23	6,30	80
Conventional	Moderate	54,28	7,08	75	65,31	7,24	75
	High	56,13	6,95	8	71,50	4,21	8
	Total	54,45	7,05	83	65,90	7,22	83
Overall Total	Moderate	54,30	6,95	154	70,44	8,41	154
	High	55,89	6,98	9	71,22	4,02	9
	Total	54,41	6,96	163	70,48	8,22	163

Both groups demonstrated improvement from pre-test to post-test, with overall mean scores increasing from 54,41 to 70,48. However, the AR-based e-book group achieved substantially higher performance gains compared to the conventional instruction group.

ANCOVA Results

ANCOVA analysis revealed a statistically significant model explaining substantial variance in learning outcomes. The overall model achieved statistical significance with $F(3,159) = 28,798$, $p < 0,001$, accounting for 35,2 % of variance in post-test scores ($R^2 = 0,352$, adjusted $R^2 = 0,340$).

Table 3. ANCOVA Summary for English Learning Performance

Source	Sum of Squares Type III	df	Mean Square	F	p	Partial η^2
Corrected Model	3856 019	3	1285 340	28 798	< 0,001	0,352
Intercept	68656 536	1	68656 536	1538 244	< 0,001	0,906
Learning Method	48,834	1	48 834	1,094	0,297	0,007
English Proficiency	0,011	1	0,011	0,000	0,988	0,000
Method × Proficiency	135 690	1	135 690	3,040	0,083	0,019
Error	7096 656	159	44 633			
Total	820610 000	163				
Corrected Total	10952 675	162				

The interaction between learning method and English proficiency approached statistical significance ($F = 3,040$, $p = 0,083$), indicating differential effectiveness of AR-based e-books across proficiency levels.

Treatment Effectiveness by Proficiency Level

Simple effects analysis revealed distinct patterns of AR effectiveness across different student proficiency levels, demonstrating the importance of considering individual differences in technology-enhanced learning interventions.

Table 4. Simple Effects Analysis by English Proficiency Level

Proficiency Level	Learning Method	M	SD	n	Mean Difference	Effect Size
Moderate	AR-based e-books	75,30	6,30	79		
	Conventional	65,31	7,24	75		
	Difference				9,99**	Large
High	AR-based e-books	69,00	-	1		
	Conventional	71,50	4,21	8		
	Difference				-2,50	Small

Note: **p < 0,01

Students with moderate English proficiency demonstrated significant benefits from AR-based e-books, achieving 9,99 points higher than their conventional learning counterparts. Conversely, high-proficiency students showed minimal differences between conditions, with traditional methods producing slightly better outcomes.

Interaction Patterns

The interaction between learning methods and English proficiency revealed a crossover pattern, indicating that AR effectiveness depends critically on student ability levels.

Figure 1 shows a cross-over interaction pattern in which lines of AR-based e-books start higher for moderate-ability students but decline for high-ability students. In contrast, conventional method lines show the opposite pattern. AR-based interactive e-books with local wisdom content show optimal effectiveness for moderate-ability students.[77] Contextual AR learning environments provide appropriate cognitive support without straining the processing capacity of moderately skilled students. The content of local wisdom serves as a bridge between familiar cultural knowledge and new English learning.[78]

High-ability students experience cognitive interference or redundancy when processing AR elements and local wisdom content simultaneously.[32,33] This happens because the student already has adequate English skills, so that additional visual and contextual information actually interferes with their learning process. These findings are in line with cognitive load theory, which states that the effectiveness of learning technology

depends on the initial knowledge and mental capacity of learners.[79,80]

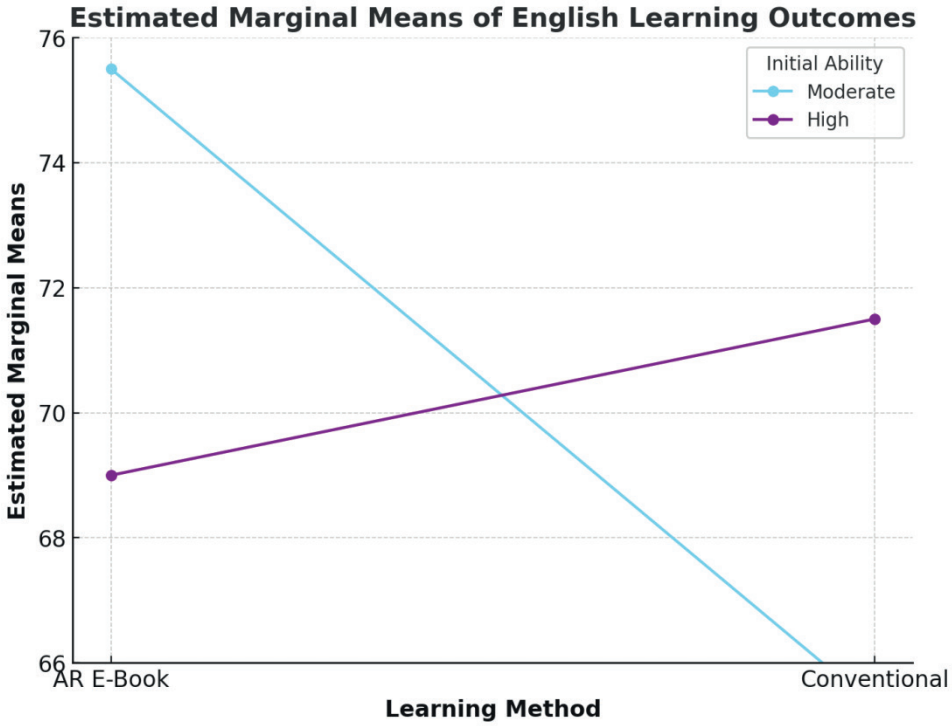

Figure 1. Estimated marginal means of English learning outcomes based on learning methods and ability level

DISCUSSION

This study aimed to evaluate the effectiveness of AR-based interactive e-books featuring South Kalimantan's local wisdom on elementary students' English learning outcomes compared to conventional teaching methods. The findings reveal significant differential effects based on student proficiency levels, providing essential insights for educational technology implementation in diverse learning environments.

Differential Effectiveness Across Proficiency Levels

The most significant finding of this research concerns the differential effectiveness of AR-based learning interventions across student proficiency levels. Students with moderate English proficiency achieved substantially greater learning gains (9,99 points) when using AR e-books compared to conventional instruction. In contrast, high-proficiency students showed minimal benefit or slight disadvantage from the AR intervention. These results align with cognitive load theory frameworks, which propose that learning effectiveness depends on the alignment between cognitive demands and learner capacity. For moderate-proficiency students, the local wisdom content functions as effective cognitive scaffolding, providing familiar cultural contexts that facilitate English vocabulary acquisition without overwhelming working memory. This finding is consistent with recent research by [81,82], who demonstrated that culturally relevant AR content enhances learning outcomes for students with intermediate skill levels.

However, our findings extend beyond previous research by demonstrating a redundancy effect for high-proficiency learners. Advanced students appear to experience cognitive interference when processing AR elements and local wisdom content simultaneously, as their existing English competence renders additional contextual support unnecessary or distracting. This redundancy effect has been observed in multimedia learning research [83] but has not been extensively documented in AR-based language learning contexts. The crossover interaction pattern observed in this study provides empirical evidence for the aptitude-treatment interaction (ATI) hypothesis in educational technology research. This finding suggests that "one-size-fits-all" approaches to AR implementation may be suboptimal, requiring instead adaptive designs that match technological complexity to learner characteristics.

Cultural Relevance and Meaningful Learning

The integration of South Kalimantan's local wisdom into AR learning materials enhances engagement and cultural connection for students, particularly those with moderate proficiency. Students demonstrated increased motivation and positive attitudes toward English learning when content reflected their cultural identity, supporting constructivist learning theories that emphasize the importance of connecting new knowledge to

prior cultural experiences. This finding contrasts with previous AR studies that employed generic or culturally neutral content.[84,85] Our results suggest that cultural embedding may be a critical factor in AR effectiveness, particularly for students in culturally rich regions like South Kalimantan. The local wisdom themes—including traditional architecture, culinary heritage, and community practices provided familiar reference points that facilitated vocabulary comprehension and contextual application.

However, our study extends beyond simple cultural relevance by demonstrating how local wisdom integration can function as cognitive scaffolding. Unlike previous research that focused primarily on motivation and engagement outcomes,[86,87] our findings provide evidence that cultural content can directly support cognitive processing for intermediate learners while potentially overwhelming advanced students.

Implications for Educational Technology Design

The differential effectiveness patterns observed in this study have significant implications for AR educational technology design and implementation. Rather than assuming universal benefits of technological innovation, our findings suggest that AR effectiveness depends critically on careful matching of content complexity, cultural relevance, and learner characteristics.

For moderate-proficiency students, AR systems should incorporate familiar cultural contexts that provide cognitive scaffolding without overwhelming working memory. Design principles should emphasize gradual complexity increase, meaningful cultural connections, and appropriate cognitive load management. These students benefit from the immersive, interactive features of AR technology when combined with culturally relevant content. Conversely, high-proficiency students may require more streamlined AR implementations that minimize extraneous cognitive load. For these learners, AR features should focus on advanced skill development rather than basic vocabulary acquisition, avoiding redundant cultural scaffolding that may interfere with efficient processing.

Comparison with Previous Research

Our findings both support and extend previous research in AR-enhanced language learning. Consistent with studies by [88,89] we found overall positive effects of AR on student engagement and learning outcomes. However, our study provides more nuanced insights by demonstrating that these benefits are not uniformly distributed across proficiency levels. Unlike previous research that reported universal AR benefits [90] our findings reveal essential limitations and potential adverse effects for specific student populations. This divergence may reflect differences in student populations, cultural contexts, or AR implementation approaches across studies.

Our cultural integration approach differs substantially from previous AR language learning research, which typically employed generic content or focused on single cultural elements. The comprehensive integration of local wisdom themes across multiple learning modules represents a novel approach that has not been extensively investigated in previous literature.

Study Limitations and Future Directions

Several limitations constrain the generalizability of these findings. First, the study focused exclusively on fifth-grade students in urban South Kalimantan schools, limiting applicability to other age groups, educational contexts, or cultural regions. The small number of high-proficiency students (n=9) also limits the statistical power for analyzing this subgroup.

Second, the study measured only immediate learning outcomes without examining long-term retention or transfer effects. Future research should employ longitudinal designs to assess whether AR learning advantages persist over time and transfer to other English learning contexts.

Third, cognitive load was not directly measured, despite theoretical arguments about its role in explaining differential effectiveness. Future studies should incorporate objective cognitive load measures to validate theoretical explanations for the observed patterns.

Fourth, the cultural specificity of local wisdom content raises questions about generalizability to other cultural contexts. Research in diverse cultural settings is needed to determine whether cultural embedding produces similar effects across different populations.

Practical Implications

These findings have important implications for educators, curriculum developers, and educational technology designers. Teachers should consider student proficiency levels when implementing AR-based learning materials, providing differentiated approaches that match technological complexity to learner needs. Curriculum developers should prioritize cultural relevance when designing AR educational content, recognizing that local cultural elements can serve essential cognitive scaffolding functions for intermediate learners. However, they should also remember that cultural content may create redundancy for advanced students.

Educational technology designers should develop adaptive AR systems that adjust content complexity and

cultural scaffolding based on real-time assessment of learner proficiency and cognitive load. Such systems could maximize benefits while minimizing the potential adverse effects of technological intervention.

CONCLUSION

This study demonstrates that AR-based interactive e-books featuring local wisdom can significantly enhance English learning outcomes for elementary students, but effectiveness varies substantially based on student proficiency levels. The research objective of evaluating AR e-book effectiveness compared to conventional methods was achieved, revealing significant differential effects that have implications for educational technology implementation. The findings contribute to educational technology theory by providing empirical evidence for aptitude-treatment interactions in AR-enhanced learning environments. Students with moderate English proficiency benefit significantly from culturally embedded AR instruction, while high-proficiency students may experience cognitive redundancy effects that limit learning gains.

From a practical perspective, these results suggest that effective AR implementation requires careful consideration of learner characteristics rather than universal application. Educational interventions should be designed to match technological complexity and cultural scaffolding to individual learner needs, maximizing benefits while avoiding cognitive overload. The integration of local wisdom into AR learning materials represents a promising approach for culturally responsive education, particularly in diverse cultural contexts like Indonesia. However, such integration must be implemented thoughtfully, with attention to individual differences in cognitive capacity and prior knowledge.

Future research should examine long-term retention effects, investigate optimal AR design principles for different proficiency levels, and explore the generalizability of cultural integration approaches across diverse educational contexts. Additionally, research incorporating direct cognitive load measurement could provide deeper insights into the mechanisms underlying differential AR effectiveness. These findings ultimately suggest that AR technology holds significant promise for elementary English education when implemented with careful attention to individual learner characteristics and cultural relevance. However, successful implementation requires moving beyond assumptions of universal technological benefits toward more nuanced, adaptive approaches that recognize the complex interactions between technology, culture, and individual differences in learning.

ACKNOWLEDGES

The author would like to thank the Directorate of Research, Technology, and Community Service, the Directorate of Research and Community Service, the Directorate General of Research and Development, and the Ministry of Higher Education, Science, and Technology for their assistance in providing facilities, infrastructure, and financial support through research grants based on the decision of the Director of Research and Community Service numbered 0419/C3/DT.05.00/2025.

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FINANCING

The authors receive financing for the development of this research from Direktorat Riset, Teknologi, dan Pengabdian kepada Masyarakat, Direktorat Penelitian dan Pengabdian kepada Masyarakat, Direktorat Jenderal Riset dan Pengembangan Kementerian Pendidikan Tinggi, Sains, dan Teknologi.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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