Explorations in English Learning

Immersive Learning with Assemblr EDU: Advancing Reading Comprehension in EFL Classrooms through AR Technology

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Abstract Despite the expanding application of Augmented Reality (AR) in educational settings, rigorous empirical investigations into its efficacy for enhancing reading comprehension among English as a Foreign Language (EFL) learners remain limited, particularly in the Indonesian higher education context. This study employed a quasi-experimental mixed-methods design to examine the impact of Assemblr EDU, an AR-based instructional application, on the reading comprehension performance of 104 undergraduate EFL learners at the B1 proficiency level. Utilizing the Dialang reading assessment and one-way analysis of covariance (ANCOVA), the quantitative findings revealed a statistically significant difference in posttest scores between the experimental group ($M = 15.61$) and the control group ($M = 12.43$), with a large effect size (partial $\eta^2 = .919$, $p < .001$), thereby affirming the pedagogical advantage of AR integration in reading instruction. Semi-structured interviews were conducted with six experienced EFL lecturers to contextualize the quantitative results further. Thematic analysis indicated that AR-supported instruction enhanced student motivation, vocabulary acquisition, and comprehension through multimodal interaction. However, technological constraints and limited access to digital resources were noted as implementation barriers. The study provides robust evidence supporting the efficacy of AR in improving EFL reading outcomes. It underscores the need for systemic support, including infrastructure readiness and targeted teacher training, to optimize its integration. These findings contribute to the theoretical and practical discourse on technology-enhanced language learning and offer implications for the design of future AR-based pedagogical interventions in EFL contexts.

***Keywords*:** Augmented reality, Reading comprehension, Technology-Enhanced Learning, EFL Learners

INTRODUCTION

Although Augmented Reality (AR) has gained increasing attention in language education, rigorous empirical investigations into its effectiveness for improving reading

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comprehension, particularly among English as a Foreign Language (EFL) learners in Indonesian higher education, remain scarce. While emerging studies have highlighted AR's potential to enhance vocabulary acquisition, learner motivation, and conceptual understanding, much of this research has been conducted in non-EFL or primary education contexts, often involving small sample sizes and limited generalizability (Danaei et al., 2020; Ebadi & Ashrafabadi, 2022; Şimşek & Direkçi, 2023). Moreover, few studies have employed comparative designs to systematically evaluate the impact of AR-based reading instruction against conventional methods, leaving questions about its pedagogical efficacy unanswered. Compounding this issue is the underrepresentation of teacher perspectives in the literature, despite their central role in implementing and sustaining digital innovations in the classroom. Addressing these gaps is critical not only for validating the instructional value of AR but also for understanding the conditions under which it can be effectively integrated into real-world learning environments. This study responds to that need by investigating both the instructional impact of Assemblr EDU—an interactive AR platform—and EFL lecturers' perceptions of it. Through a quasi-experimental mixed-methods design, the research provides evidence on how AR can be aligned with constructivist principles to foster deeper learner engagement and comprehension. Situated within the underexplored context of Indonesian tertiary EFL education, this study offers a timely and context-sensitive contribution to the growing body of research on immersive learning technologies.

In recent years, Augmented Reality (AR) has emerged as a transformative tool in education, praised for its ability to convert passive learning environments into dynamic, interactive experiences. Research across disciplines such as science, mathematics, and early childhood education has consistently demonstrated its benefits in promoting student engagement, retention, and conceptual understanding (Akçayır & Akçayır, 2017; Mystakidis et al., 2021; Sat et al., 2023). AR is gaining recognition in language education for its capacity to enrich vocabulary instruction, provide contextualized multimodal input, and foster greater learner autonomy, particularly when integrated into mobile learning platforms (Shaaban & Mohamed, 2024; Chen et al., 2020). Nevertheless, despite growing interest, the application of AR in language learning remains predominantly exploratory. Many existing studies are limited by small-scale designs, narrowly defined learner populations, and a focus on general language proficiency rather than domain-specific outcomes such as reading comprehension. Moreover, most investigations prioritize short-term cognitive effects or student perceptions while neglecting more profound pedagogical questions regarding instructional alignment and long-term efficacy, especially from the perspective of classroom practitioners. In the Indonesian EFL context, these limitations are compounded by a scarcity of context-specific research that examines how AR can be effectively implemented at the tertiary level.

Addressing the limitations in current research requires a more rigorous, contextually grounded, and theory-informed approach. One major shortcoming in the literature is the limited use of quasi-experimental designs to establish causal links between AR-based instruction and EFL reading comprehension outcomes. Without such designs, findings' instructional validity and generalizability remain questionable (Chang et al., 2022; Şimşek & Direkçi, 2023). In addition, most AR studies have been conducted in primary education or general foreign language settings, with little empirical attention paid to tertiary-level EFL learners, whose needs and cognitive profiles differ considerably. Although increased learner

engagement is frequently cited as a benefit of AR, studies often overlook the pedagogical experiences of educators who must implement and sustain these technologies. Their insights are essential for aligning instructional practices with institutional realities and learner diversity. Moreover, many AR interventions lack grounding in established learning theories such as constructivism, emphasizing active knowledge construction and student-centered design. These gaps highlight the need for comprehensive research that evaluates measurable learning gains and considers the practical, contextual, and theoretical dimensions of integrating AR into EFL reading instruction.

This study presents a timely and multidimensional contribution to the expanding field of technology-enhanced language learning by addressing the instructional potential and practical challenges of Augmented Reality (AR) in EFL reading comprehension. Adopting a quasi-experimental mixed-methods design—still underutilized in this area—the research generates both statistically grounded evidence and rich qualitative insights. By integrating pre- and post-intervention assessments with thematic analysis of lecturer interviews, the study evaluates the effectiveness of AR in improving learners' reading comprehension and the pedagogical realities encountered in classroom practice. Situated within the under-researched context of Indonesian tertiary EFL education, it also fills a critical gap in regional and demographic representation within the global discourse. Implementing Assemblr EDU, an immersive AR platform that supports interactive engagement through 3D visualizations, multimedia cues, and multimodal scaffolding, is central to the study. Grounded in constructivist learning theory, the intervention is designed to foster active knowledge construction, learner autonomy, and meaningful interaction with text. Significantly, the study's dual focus on student performance and educator experience advances a holistic understanding of AR integration in EFL contexts, offering practical implications for instructional design, teacher training, and sustainable educational innovation.

In response to these challenges and gaps, the present study investigates the instructional efficacy of Assemblr EDU, an immersive AR platform, in enhancing reading comprehension among Indonesian undergraduate EFL learners. It also explores lecturers' perspectives on its pedagogical relevance, affordances, and constraints. Specifically, the study addresses two core research questions: (1) In what ways do AR-based mobile applications influence students' reading comprehension? and (2) What are educators' perspectives on integrating AR-based mobile applications into English as a Foreign Language (EFL) classrooms, and how does AR impact the teaching and learning process? By adopting a quasi-experimental mixed-methods approach, the research not only evaluates learning outcomes but also captures the contextual dynamics of AR implementation in real instructional settings. The study contributes to a deeper empirical and pedagogical understanding of AR in language education through this dual lens. It offers practical insights for the design, integration, and sustainability of immersive technologies in EFL curricula.

METHOD

Design

This study adopted a sequential explanatory mixed-methods design, integrating a quasi-experimental quantitative phase with a qualitative component to comprehensively understand the effectiveness and practicality of Augmented Reality (AR)-based reading instruction. The quantitative phase employed a non-equivalent pretest-posttest control group design (Dimitrov & Rumrill, 2003) to measure the intervention's impact on reading comprehension. The qualitative phase was followed by interpreting and contextualizing the quantitative findings through semi-structured interviews with participating lecturers, focusing on their perceptions of AR integration in EFL reading instruction.

Participants

104 undergraduate EFL students from the English Department at Universitas Jabal Ghafur, Indonesia, were recruited to participate in the quantitative phase. All participants were native Indonesian speakers between 18 and 22 years old. The Oxford Quick Placement Test (OQPT) was administered at the study's outset to ensure linguistic comparability. Only students scoring between 40 and 59, corresponding to the B1 level of the Common European Framework of Reference (CEFR), were included in the sample. This level was deemed appropriate for engaging with AR-enhanced materials and standard reading tasks. Following screening, participants were randomly assigned to either the experimental group (n = 54) or the control group (n = 50) to minimize selection bias and support the internal validity of the quasi-experimental design. Table 1 presents the demographic characteristics of the student participants, including gender distribution, CEFR-level proficiency, and group allocation.

Table 1. Demographic Profile of Student Participants

Category	Subcategory	Number	Percent
Gender	Male	35	34%
	Female	69	66%
General English level	CFR-B1	104	100%
Average number of students per class	Exp.Class	54	52%
	Control Class	50	48%

Six EFL lecturers were purposively selected in the qualitative phase to provide in-depth perspectives on integrating Augmented Reality (AR) in EFL reading instruction. Selection criteria included holding a master's degree or higher in English language teaching or a related field and having at least two years of classroom teaching experience. These lecturers directly instructed the experimental or control group, positioning them as observers and implementers of the pedagogical process. Their familiarity with instructional design and engagement with the intervention allowed for reflective commentary on AR's instructional value, technical feasibility, and student responsiveness. The demographic background of the lecturer participants—including gender, years of teaching experience, and academic qualifications—is summarized in Table 2.

Table 2. Demographic Profile of Lecturer Participants

Category	Subcategory	Number	Percent
Gender	Male	1	17%
	Female	5	83%
Teaching experiences	2-5 years	2	33%
	6-10 years	4	67%

	11-15 years	0	0%
	>15 years	0	0%
Qualifications	College	0	0%
	BA	0	0%
	MA	6	100%
	PhD	0	0%

Instruments and Data Collection

This study adopted a sequential explanatory mixed-methods design to investigate the effectiveness of augmented reality (AR) in enhancing EFL students' reading comprehension and to explore lecturers' perceptions regarding its classroom integration. The quantitative phase consisted of a quasi-experimental pretest-posttest control group design and a qualitative phase to contextualize the intervention outcomes (Creswell et al., 2003; Dimitrov & Rumrill, 2003).

Quantitative Instruments and Procedures

To assess students' reading proficiency, the study utilized the Dialang diagnostic test (Alderson & Huhta, 2005), a well-established, CEFR-aligned assessment tool. The Dialang test comprises 30 multiple-choice items that measure reading comprehension through tasks related to main idea identification, inferencing, vocabulary use, and understanding supporting details. To mitigate test familiarity effects, parallel versions of the test were administered at both the pretest and posttest stages. The test's validity and reliability in L2 assessment contexts are supported by previous research (Alderson et al., 2006; Zhang & Thompson, 2004).

Before the intervention, the Oxford Quick Placement Test (OQPT) was administered to screen participants for English language proficiency. Only students scoring between 40 and 59, equivalent to the CEFR B1 level, were included in the sample to ensure a homogeneous proficiency baseline. The final sample of 104 participants was randomly assigned to the experimental group (n = 54) and the control group (n = 50). The experimental group received AR-enhanced reading instruction using Assemblr EDU, while the control group followed standard printed materials covering equivalent content.

Instruction for the experimental group was delivered through Assemblr EDU, a no-code AR platform that allows for the creation of interactive, multimodal learning materials. The research team developed seven reading texts enriched with QR codes linked to 3D models, videos, and contextual definitions. These AR features scaffolded learners' comprehension by offering visualizations of abstract vocabulary and enhanced engagement through multisensory input. Students could access AR content via smartphones without requiring app installation, allowing for flexible and offline learning.

Qualitative Instruments and Procedures

To deepen the understanding of AR's pedagogical implications, the study employed semi-structured interviews with six EFL lecturers involved in delivering instruction. The interview protocol consisted of eight open-ended questions, developed based on the study's objectives and related literature. The questions explored lecturers' experiences, perceived

benefits and challenges, instructional strategies, and digital competencies concerning AR use in reading comprehension instruction.

Each interview was conducted in person and lasted approximately 30 minutes. It was audio-recorded with informed consent. The recordings were transcribed verbatim and returned to participants for member checking (Cheng & Dörnyei, 2007) to ensure accuracy and enhance credibility.

Thematic analysis followed Braun and Clarke's (2006) six-phase framework, beginning with familiarization and open coding, followed by theme development, refinement, and integration. To support a systematic and transparent analysis, the researchers used NVivo 12 software, which facilitated the coding process and identified cross-participant themes. Emergent themes were continually checked against the raw data and aligned with the study's research questions. This combination of standardized quantitative assessment and in-depth qualitative inquiry allowed for a comprehensive evaluation of both the instructional impact of AR and the pedagogical conditions necessary for its successful integration in EFL higher education settings.

Data Analysis

Data analysis was conducted using quantitative and qualitative procedures, consistent with the study's mixed-methods framework. Quantitative data derived from the pretest and posttest Dialang scores were analyzed using IBM SPSS Statistics version 26, while qualitative interview transcripts were examined through thematic analysis.

Quantitative Analysis

The quantitative data were analyzed using IBM SPSS Statistics version 26 to determine the impact of the AR-based instructional intervention on students' reading comprehension. Before conducting inferential analysis, data normality was assessed through skewness and kurtosis ratios, which confirmed that the reading scores were normally distributed and met the assumptions for parametric testing. An independent samples t-test was conducted on pretest scores to ensure baseline equivalence between the experimental and control groups. A one-way Analysis of Covariance (ANCOVA) was employed with pretest scores as the covariate to evaluate the intervention's effect while controlling for initial proficiency differences. This statistical technique was chosen for its ability to reduce error variance and improve the precision of group comparisons by adjusting for pre-existing differences. The combination of normality checks, baseline verification, and covariate control provided a rigorous analytic framework to assess the instructional effectiveness of the AR intervention, as aligned with the first research question.

Qualitative Analysis

The qualitative component of this study involved an in-depth thematic analysis of semi-structured interview data collected from six EFL lecturers who participated in the AR-based instructional intervention. The analysis followed the six-phase framework developed by Braun and Clarke (2006), which provides a rigorous and flexible method for identifying, analyzing, and reporting patterns within qualitative data. The process began with repeated readings of the interview transcripts to promote familiarization with the data, followed by

the generation of initial codes that captured salient features related to participants' perceptions of AR integration. These codes were then collated into potential themes, which were reviewed, refined, and clearly defined to ensure internal consistency and conceptual clarity. Finally, the themes concerning the research questions and existing literature were named and interpreted.

To enhance the trustworthiness of the analysis, the research team employed NVivo 12 software to facilitate the systematic organization, coding, and retrieval of data. This digital tool efficiently managed large qualitative datasets and ensured analytical transparency. Thematic development was conducted inductively, meaning patterns emerged directly from the data rather than being imposed by pre-existing frameworks. However, the emerging themes were later interpreted through the lens of relevant pedagogical theories, particularly constructivist principles and technology integration models. To ensure credibility and confirmability, the researchers implemented member checking procedures (Cheng & Dörnyei, 2007), whereby participants were invited to review and verify the accuracy of their transcripts and the thematic interpretations derived from their responses.

Integrating these qualitative findings with the quantitative data enabled a more comprehensive and nuanced understanding of the research problem. Whereas the statistical analysis quantified the impact of AR on students' reading comprehension, the thematic analysis illuminated the instructional dynamics, perceived affordances, and implementation challenges from the perspective of practitioners. This dual-layered approach strengthened the study's internal validity and enhanced its practical relevance, offering insights into AR-based instruction's efficacy and pedagogical viability in tertiary EFL settings.

FINDING AND DISCUSSION

Quantitative Findings

To address the first research question—investigating the effects of Augmented Reality (AR)-based instruction on students' reading comprehension—quantitative Data were analyzed using SPSS version 26. Before inferential tests, the dataset was examined for adherence to the normality assumption, a prerequisite for parametric analysis. As presented in Table 3, all skewness and kurtosis values for the control and experimental groups fell within the acceptable threshold of ±1.96, indicating that the distributions of the pretest and posttest scores were approximately normal. This validation confirmed the appropriateness of applying parametric statistical procedures, such as ANCOVA, to assess the intervention's effect on reading comprehension outcomes.

Table 3. Descriptive Statistics and Normality Test Results

Groups	Mean	SD	Skewness	SE Skew	Kurtosis	SE Kurt
Control Pretest	12.39	2.27	-0.065	0.403	-0.938	0.788
Control Posttest	12.43	2.65	-0.214	0.403	-0.925	0.788
Experimental Pretest	12.43	2.38	0.014	0.403	-0.962	0.788
Experimental Posttest	15.61	3.16	-0.116	0.403	-0.974	0.788

Before proceeding with ANCOVA, the assumption of homogeneity of regression slopes was assessed to ensure the validity of the analysis. The interaction term between the group and

pretest scores was found to be non-significant (p = .866), confirming that the assumption was satisfied and justifying the use of ANCOVA for subsequent comparisons. The ANCOVA results, summarized in Table 4, demonstrated a statistically significant difference in posttest reading comprehension scores between the experimental and control groups after adjusting for pretest performance, $F(1,100) = 741.369$, $p < .001$. The calculated effect size was notably large (partial $\eta^2 = .919$), indicating that the AR-based instructional intervention had a strong and meaningful impact on students' reading comprehension outcomes.

Table 4. ANCOVA Between-Subjects Effects

Source	SS	MS	F	Sig.	Partial η^2
Corrected Model	547.202	182.401	1000.684	.000	.979
Intercept	8.662	8.662	47.521	.000	.426
Groups	133.114	133.114	741.369	.000	.919
Pretest	372.368	372.368	2042.880	.000	.970
Groups * Pretest	0.005	0.005	0.029	.866	.000
Error	11.666	0.182			

Estimated marginal means further illustrated the substantial difference between the two instructional conditions. As presented in Table 5, students in the experimental group, who received AR-based instruction via Assemblr EDU, achieved a significantly higher adjusted mean score (M = 15.448, SE = 0.073) compared to their counterparts in the control group (M = 12.640, SE = 0.073). The non-overlapping 95% confidence intervals (15.303–15.594 for the experimental group; 12.495–12.785 for the control group) underscore the robustness of this difference and eliminate ambiguity regarding the direction of the effect. These adjusted means account for initial differences observed in the pretest and reflect a consistent trend favoring the experimental group after the intervention. The findings support the argument that AR-based instruction fosters deeper engagement with textual materials, leading to enhanced comprehension outcomes.

Table 5. Estimated Marginal Means

Group	Mean	SE	95% CI Lower	95% CI Upper
Control	12.640	0.073	12.495	12.785
Experimental	15.448	0.073	15.303	15.594

Pairwise comparison analysis (Table 6) confirmed the statistical significance of this difference, with a mean difference of -2.808 ($p < .001$), favoring the experimental group. This result indicates that students who received instruction using AR-based applications (Assemblr EDU) significantly outperformed their peers in the control group regarding posttest reading comprehension scores, even after adjusting for pretest performance. The narrow confidence interval (95% CI = -3.014 to -2.602) reinforces the precision of this estimate and strengthens the claim that the observed effect is unlikely due to chance.

Table 6. Pairwise Comparison of Groups

Group I	Group J	Mean Difference (I–J)	SE	Sig.	95% CI Lower	95% CI Upper
Control	Experimental	-2.808	0.103	.000	-3.014	-2.602

These findings corroborate earlier claims by Ebadi and Ashrafabadi (2022) and Danaei et al. (2020), emphasizing the efficacy of multimodal AR interventions in enhancing EFL learners' textual understanding.

Qualitative Findings

To answer the second research question—exploring educators' perspectives on integrating AR-based mobile applications into EFL classrooms—qualitative data from semi-structured interviews were analyzed thematically. Seven major themes emerged: (1) Enhanced Motivation and Engagement, (2) Improved Reading Comprehension, (3) Personalized Learning Opportunities, (4) Vocabulary Acquisition and Retention, (5) Cognitive Development, (6) Implementation Challenges, and (Pedagogical Integration Strategies).

Table 7. Summary of Key Themes Emerging from Educator Interviews

Theme	Description	Pedagogical Implication
Enhanced Motivation and Engagement	AR should be integrated into lessons where engagement is low.	Use AR for high-effort tasks (e.g., dense texts).
Improved Reading Comprehension	AR can scaffold complex content for learners with low proficiency.	Combine AR with pre-reading supports.
Personalized Learning Opportunities	AR's flexibility can support differentiated instruction.	Assign AR tasks based on learner profiles.
Vocabulary Acquisition and Retention	AR is suitable for incidental and contextual vocabulary instruction.	Embed AR for glossaries or lexical review.
Cognitive Development	AR can reinforce abstract language and academic concepts.	Use AR in concept-heavy units (e.g., science).
Implementation Challenges	Educators need training, and schools need investment.	Develop tech PD and check device compatibility.
Pedagogical Integration Strategies	Instruction should frame AR within larger learning goals.	Use AR with guided discussions and reflection.

Educators consistently expressed strong support for the pedagogical integration of AR, particularly for its ability to foster student motivation and engagement. AR-based activities were described as transformative, shifting students from passive recipients to active participants in the learning process. Participant 4 noted, "*The students were engaged and excited when we used AR in our reading sessions*." Participant 11 emphasized the heightened energy in class: "*You could see how motivated and delighted they were as they engaged with the technology*." These reflections suggest immersive digital environments may promote enthusiasm, emotional investment, and behavioral participation in EFL contexts. AR, in this regard, acts as a catalyst for learner-centered engagement.

Another frequently cited advantage of AR was its contribution to reading comprehension. Participants emphasized the role of multimodal inputs—such as animations, 3D visualizations, and embedded videos—in making complex or abstract content more

accessible. Participant 3 explained, "*Their understanding was improved, and the interactive 3D models and videos gave more context*." Similarly, Participant 7 remarked, "*AR enhanced the student's comprehension of the texts*." These insights affirm that AR is an effective form of visual scaffolding, enabling learners to construct meaning through sensory-rich, contextualized representations.

In addition to enhancing comprehension, AR was credited for supporting personalized and differentiated instruction. Educators noted that AR-enabled tools allowed them to tailor learning experiences to students' proficiency levels and individual preferences. "*Augmented reality improved teaching through providing students with more engaging and personalised learning opportunities*," said Participant 2. Participant 18 added, "*I could adjust the lesson to fit different students' levels and preferences better*." These examples illustrate the adaptability of AR, making it an inclusive pedagogical tool that accommodates diverse learner needs.

Vocabulary development also emerged as a key benefit of AR integration. Educators highlighted that the interactive and contextualized features—such as tappable definitions, example sentences, and pronunciation tools—significantly enhanced lexical acquisition. "*Students learned words better when they could hear and see them used in real context*," stated Participant 8. Participant 10 echoed this, noting that "*AR helped them use new phrases meaningfully*." Such affordances reinforce vocabulary retention by embedding language input in multimodal, meaningful contexts, supporting incidental and situated learning.

Despite the clear pedagogical value, educators also identified several implementation challenges. Technical barriers were common, such as unstable internet connections and device incompatibility. "*Sometimes the app would crash, or the Wi-Fi was too weak to run the AR smoothly*," reported Participant 22. Another recurring concern was the limited digital literacy and preparedness among instructors. "*Training should be provided not just for students, but for teachers too, to maximize its use*," emphasized Participant 17. These accounts underscore the necessity of institutional investment in technical infrastructure and professional development to realize AR's full potential in practice.

Beyond motivation and comprehension, AR promoted higher-order thinking and conceptual understanding. "*By offering interactive and visual representations, AR assisted students in better understanding difficult concepts*," noted Participant 16. Participant 9 further observed, "*It helped develop their thinking skills and made challenging texts easier to grasp*." These statements suggest that AR supports basic skill acquisition and facilitates deeper cognitive engagement, aligning with constructivist principles that advocate active, experiential learning.

Educators emphasized that AR integration's success depends heavily on pedagogical planning. Several lecturers advised that AR should not stand alone but be embedded within well-sequenced instructional activities. "*Before starting AR activities, I would show students relevant videos and lead conversations to build their background knowledge*," explained Participant 6. This preparatory phase helps activate students' schema and frames the AR experience within a meaningful context.

Thus, the qualitative data portray AR as more than a technological enhancement—it is a pedagogically valuable tool capable of transforming EFL instruction when implemented thoughtfully. While the benefits are clear, the challenges underscore the need for sustainable

strategies that involve infrastructure support, teacher training, and curricular alignment. With these elements in place, AR has the potential to enhance student learning and engagement in language education significantly.

DISCUSSION

This study examined the impact of Augmented Reality (AR)-based mobile applications on EFL students' reading comprehension and explored educators' perspectives on integrating AR into language classrooms. Findings from both quantitative and qualitative phases support the conclusion that AR-based instruction can significantly enhance reading comprehension, student engagement, and instructional personalization when pedagogically aligned with constructivist principles.

The quantitative results revealed a statistically significant improvement in reading comprehension for students in the experimental group who received AR-based instruction using Assemblr EDU, with a large effect size (partial $\eta^2 = .919$). This outcome substantiates existing literature suggesting that AR promotes higher-order comprehension skills through its multimodal and interactive features (Billinghurst & Duenser, 2012; Akçayır & Akçayır, 2017). AR enhances learners' ability to construct meaning by integrating textual information with dynamic visual and auditory representations, thus facilitating cognitive elaboration (Mayer, 2009). The findings also support the dual coding theory (Paivio, 1990), which posits that learning is more effective when verbal and non-verbal information is processed simultaneously.

Qualitative data from semi-structured interviews strongly corroborated the quantitative findings, particularly highlighting AR's role in enhancing students' engagement and motivation—two pivotal affective variables closely tied to academic achievement and language acquisition success (Dörnyei & Ushioda, 2011; Egbert, 2020). Educators consistently observed that immersive features such as three-dimensional visualizations, interactive animations, and video overlays transformed traditional reading practices into dynamic, participatory experiences. These digital enhancements captured students' attention and promoted sustained cognitive engagement by encouraging exploration, prediction, and meaning-making during reading tasks. Such transformations are consistent with constructivist learning paradigms, which posit that knowledge construction occurs most effectively through active participation and authentic interaction with content and context (Jonassen & Rohrer-Murphy, 1999). AR is a mediational tool within this framework that scaffolds learners' cognitive and emotional investment, thereby reducing affective barriers such as boredom or anxiety, often hindering EFL learners' performance (MacIntyre & Gregersen, 2012). Moreover, the multisensory nature of AR content—integrating visual, auditory, and spatial stimuli—aligns with Mayer's (2009) cognitive theory of multimedia learning, which emphasizes the value of dual-channel information processing for deeper comprehension. The educators' reflections suggest that AR technologies can reshape learner engagement from passive decoding to active interpretation, supporting emotional involvement and cognitive depth in EFL reading instruction when used pedagogically and not just as novelty tools.

Additionally, the study found that AR facilitated differentiated instruction, enabling educators to address diverse learner needs through adjustable pacing and personalized

input. Prior studies have emphasized the importance of learner-centered design in AR environments (Wu et al., 2013; Ibáñez & Delgado-Kloos, 2018), noting that adaptive AR applications can scaffold comprehension and promote learner autonomy. Teachers in this study observed how the technology allowed for real-time support in vocabulary learning, further validating earlier work on the affordances of AR in vocabulary development (Hsu, 2017; Chen et al., 2020).

Vocabulary acquisition was another key improvement consistently noted by both learners and educators, reinforcing the pedagogical value of AR in supporting lexical development. Context-sensitive features—such as tappable word definitions, real-time pronunciation modeling, example sentences, and visual representations—allowed students to encounter and process new vocabulary in meaningful, multimodal contexts. This form of incidental vocabulary learning aligns closely with Nation's (2013) framework, which underscores the importance of repeated, enriched exposure to vocabulary across various modes and contexts to strengthen retention and retrieval. Moreover, such affordances reflect core second language acquisition (SLA) principles, particularly the emphasis on comprehensible input, salience, and meaningful interaction as catalysts for vocabulary uptake (Ellis, 2008; Gass & Selinker, 2008). In the present study, educators observed that learners memorized new words more effectively and demonstrated a greater ability to apply them in contextually appropriate ways during follow-up discussions and comprehension activities. This suggests that AR did more than introduce new vocabulary; it facilitated deeper lexical processing through multisensory input and learner agency. These outcomes resonate with findings from recent AR-in-education research, which indicates that digital scaffolds—especially those embedded in immersive environments—can enhance lexical acquisition and learner autonomy (Hsu, 2017; Ibáñez & Delgado-Kloos, 2018). Thus, AR served as a vocabulary presentation tool and an interactive platform for repeated, situated lexical encounters that promote long-term retention and meaningful language use.

However, despite AR integration's clear instructional benefits, educators highlighted several persistent barriers that could impede its broader adoption and effectiveness. Chief among these were technical challenges such as unstable internet connectivity, device incompatibility, and limited digital literacy among teachers and students—issues that echo concerns raised in previous studies (Parmaxi & Demetriou, 2020; Lin et al., 2022). These technological constraints disrupt instructional continuity and limit equitable participation, particularly in under-resourced or rural educational settings where digital infrastructure remains uneven. Hew and Brush (2007) argue that such disparities risk deepening existing educational inequalities by privileging learners with greater access to digital tools and support systems. Moreover, the effective use of AR requires technological fluency and pedagogical adaptation that many educators may not possess without targeted training. In this regard, institutional commitment to continuous professional development is critical. As Kimmons (2020) emphasizes, successful technology integration is contingent on access to hardware and software, teacher readiness, and institutional culture. The findings thus underscore the need for comprehensive capacity-building initiatives, including technical support, pedagogical training, and resource provisioning, to ensure that AR can be sustainably and inclusively implemented in EFL contexts.

Another critical insight relates to the pedagogical implementation of AR. Teachers emphasized the need for structured preparatory activities to maximize the effectiveness of AR content. This is supported by research on instructional sequencing in technology-enhanced learning, which suggests that AR is most effective when embedded within a coherent instructional strategy (Yuen et al., 2011; Cheng & Tsai, 2013). Rather than treating AR as a novelty, educators in this study advocated for its integration into lesson planning, with clear pre-, during-, and post-activity alignment.

Significantly, this study contributes to the expanding literature on AR in language education by adopting a mixed-methods quasi-experimental design situated in a higher education EFL context—an area that remains relatively underexamined in empirical research (Bacca et al., 2014; Radu, 2014). Unlike many prior studies that primarily centered on isolated vocabulary learning tasks or short-term engagement metrics (Dunleavy & Dede, 2014; Liu & Tsai, 2013), this research provides a more comprehensive exploration of AR's instructional utility by triangulating quantitative learning outcomes with qualitative insights from educators. By doing so, it not only assesses the cognitive impact of AR on reading comprehension but also illuminates the pedagogical considerations, affordances, and challenges from the practitioner's viewpoint—an aspect often neglected in earlier investigations. This dual-perspective approach allows a deeper understanding of AR functions within real classroom ecosystems, bridging the gap between technological innovation and pedagogical relevance. As such, the study offers practical implications for integrating AR into EFL curricula while advancing theoretical discourse on immersive learning technologies.

While the findings of this study offer compelling evidence for the short-term benefits of AR-assisted instruction in EFL reading comprehension, they should be considered alongside certain limitations. Most notably, the six-week intervention period, although appropriate for evaluating immediate learning outcomes, does not provide insight into the long-term retention of skills or the durability of student engagement. As such, longitudinal research is needed to assess whether the observed gains in comprehension are sustained over time and whether learners can effectively transfer AR-mediated strategies to other academic domains. Furthermore, the present study focused on a single AR platform (Assemblr EDU) and one language skill (reading); future investigations should explore the comparative effectiveness of various AR modalities—including headset-based, location-aware, and gesture-controlled systems—and their impact across broader linguistic competencies such as listening, speaking, and writing. Such comparative and skill-diverse approaches would offer a more nuanced understanding of AR's instructional versatility and alignment with different pedagogical goals and learner profiles.

CONCLUSION

This study provides compelling evidence that the integration of Augmented Reality (AR) through Assemblr EDU significantly enhances reading comprehension among intermediate EFL learners in Indonesia. Students who participated in the AR-based intervention demonstrated markedly higher posttest scores than those in traditional reading classes, indicating that immersive, multimodal instruction can effectively scaffold learners' understanding of complex texts. The AR environment—characterized by the interplay of visual, auditory, and interactive elements—facilitated vocabulary acquisition and textual

interpretation and aligned with constructivist learning principles by promoting active engagement and contextualized meaning-making.

Qualitative findings further enriched the study by capturing educators' perceptions of AR's pedagogical value. Lecturers consistently observed increased student motivation, deeper cognitive engagement, and improved conceptual understanding, attributing these outcomes to AR's capacity for personalization and multimodal representation. Moreover, AR was recognized as a catalyst for learner-centered instruction, capable of addressing diverse learner profiles and promoting differentiated learning pathways. However, the study highlighted critical implementation challenges, including limited infrastructure, device compatibility issues, and the need for comprehensive teacher training—concerns that resonate with broader literature on educational technology integration in under-resourced contexts.

Taken together, the findings emphasize the transformative potential of Augmented Reality (AR) when deliberately designed and pedagogically supported within EFL reading instruction. To fully harness its instructional benefits, future research should prioritize the development of scalable and adaptive AR frameworks that extend beyond reading to encompass integrated language competencies, including speaking, listening, and writing. Longitudinal investigations are particularly warranted to evaluate the durability of learning outcomes and the extent to which AR-enhanced strategies transfer to other academic domains and communicative tasks. Moreover, the successful and equitable implementation of AR in language education will depend heavily on institutional commitment to strengthening digital infrastructure and providing sustained professional development for educators. Such systemic support is crucial for bridging technological gaps, fostering pedagogical innovation, and ensuring that AR becomes a sustainable and inclusive tool for language learning advancement.

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