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Research Article

The Impact of Mobile Augmented Reality on Vocabulary Acquisition, Learner Engagement, and Experience in Higher Education

Nofvia De VEGA[1*]
Syarifa RAFIQA[2]

Corresponding author: nofviadevega@borneo.ac.id
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ABSTRACT

The primary objectives of this study were to (1) assess the effectiveness of a Mobile Augmented Reality (AR)-based English learning program and (2) provide a human-centered analysis of students lived experiences within this innovative pedagogical setting. This work fills a critical research gap where much of the existing literature on AR in language learning emphasizes quantifiable results at the expense of students' subjective experiences and challenges. Utilizing a convergent parallel mixed-methods design, this study quantified English proficiency improvements and explored student experiences (interviews/observations). 173 diverse students engaged with a Mobile AR program featuring interactive 3D visualizations and customized content to enhance overall English, vocabulary, and grammar skills. The primary outcomes revealed a statistically significant and practically substantial positive impact of the AR intervention across all English language proficiency measures ($p < 0.001$; Cohen's $d > 1.95$; N-gain 0.74-0.75). Qualitative findings indicated that Mobile AR significantly enhanced comprehension through visualization, substantially increased learning interest and immersion, and fostered a deeper understanding of English's practical relevance through major-specific content. However, students reported challenges, notably technical issues such as device compatibility problems and occasional unstable internet connectivity. Future research should prioritize optimizing AR integration strategies and infrastructure development for wider, sustainable pedagogical application.

Keywords: *Mobile, Augmented Reality (AR), English Language Learning, Language Proficiency, Student Experience*

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[1] *Universitas Borneo Tarakan*, INDONESIA. Email: nofviadevega@borneo.ac.id
ORCID: https://orcid.org/0000-0002-8373-7192
[2] *Universitas Borneo Tarakan*, INDONESIA. Email: rafiqa@borneo.ac.id
ORCID: https://orcid.org/0000-0002-3160-6799

INTRODUCTION

In the contemporary educational landscape, English language proficiency stands as an indispensable competency, crucial for both academic advancement and professional success in an increasingly interconnected world. The imperative to foster effective learning outcomes and robust learner engagement has thus propelled the exploration of innovative pedagogical approaches. Within this context, Mobile Augmented Reality (AR) technology has emerged as an up-and-coming tool, demonstrating significant potential to transform the learning experience fundamentally (Biswas & Ghosal, 2025; Lavingia & Tanwar, 2020). By seamlessly overlaying virtual information onto real-world environments, AR facilitates immersive and interactive learning opportunities, thereby cultivating visual and experiential understanding that often transcends the limitations of traditional instructional methods.

"AR technology enriches English language acquisition and guides future education from a human-centered perspective"

Ji et al. (2025); Papanastasiou et al. (2019); Pramanik (2024) highlights AR's profound impact on enhancing learners' visual comprehension, stimulating intrinsic interest, and fostering deep immersion in educational content. For instance, the strategic deployment of 3D models and dynamic animations within AR-based learning environments has been shown to significantly aid students in grasping abstract English concepts and complex vocabulary (Rozi et al., 2021). This phenomenon is well-supported by Luo (2022), which posits that information is more effectively processed, retained, and recalled when encoded through both verbal and non-verbal (visual) channels, creating distinct yet interconnected mental representations. Furthermore, the inherently interactive and captivating nature of AR applications frequently transforms the learning process into an engaging, game-like experience, substantially elevating student participation and intrinsic motivation. This heightened engagement can be comprehensively understood through the lens of Ryan & Deci (2018), wherein the autonomy and competence fostered by interactive Mobile AR environments contribute directly to the cultivation of intrinsic motivation. Similarly, AlGerafi et al. (2023); Shin (2019) suggests that the immersive quality inherent in AR can induce a state of complete absorption, thereby sustaining concentration and amplifying enjoyment throughout the learning process.

Moreover, empirical studies indicate that tailoring AR content to align with specific academic disciplines or professional contexts enhances the perceived relevance and practical utility of English language acquisition, demonstrating its direct applicability within a student's chosen field. It aligns precisely with Zhang & Miao (2025), which underscores that learning is most profound and compelling when deeply embedded within authentic, context-rich environments pertinent to the learner's experiences and future aspirations.

While this capacity of tailored Mobile AR content to foster such profound and compelling learning experiences by deeply embedding English within authentic, context-rich environments is evident, a critical gap persists in the comprehensive evaluation of its real-world effectiveness and, more importantly, in the nuanced understanding of the student experience within Mobile AR-based learning programs, a critical gap persists in the comprehensive evaluation of its real-world effectiveness and, more importantly, in the comprehensive understanding of the multifaceted student experience, particularly how students navigate engagement challenges, adapt to AR-specific pedagogical demands, and cope with practical implementation challenges such as device compatibility and connectivity in real-world settings (Zeicu et al., 2025). Prior research, while valuable, has often predominantly focused on quantitative performance metrics or has offered anecdotal insights into individual learning experiences (Nauta et al., 2023). However, these studies frequently overlook or insufficiently address the practical implementation challenges inherent in AR deployment, such as issues related to device compatibility, application stability, and reliable network connectivity. Such technical and logistical factors can profoundly influence the overall learning experience, yet their systemic impact has rarely been investigated with sufficient depth. It highlights a crucial need to transcend mere measurement of learning gains and to instead embrace a holistic inquiry into the student journey, encompassing both the triumphs and the obstacles encountered. This gap underscores the paramount importance of ecological validity in educational research, ensuring that findings are robust, generalizable, and truly applicable to diverse, real-world learning environments.

To systematically address this identified research gap, the present study proposes a comprehensive investigation into the efficacy of a Mobile AR-based English learning program. Crucially, this research aims not only to quantify its impact but also to gain an in-depth, qualitative understanding of students' lived experiences within this innovative learning environment. This study employed a mixed-methods approach, integrating both quantitative and qualitative data collection and analysis. The quantitative component will rigorously measure improvements in overall English language proficiency, vocabulary acquisition, and grammatical accuracy. Concurrently, the qualitative component systematically gathered through in-depth student interviews and direct observations will be utilized to explore learners' subtle perceptions, capture immediate feedback, and identify the contextual factors that influence their learning trajectory. This integrated approach allows for a synergistic understanding, leveraging the strengths of both methodologies. Therefore, this study aims to: (1) assess the effectiveness of a Mobile AR-based English learning program on English language proficiency, particularly vocabulary acquisition and student engagement. (2) provide a human-centered analysis of students' lived experiences, including their perceptions, challenges, and adaptation within this innovative pedagogical setting.

LITERATURE REVIEW

Augmented Reality in Education

Augmented Reality, distinct from virtual reality, enhances the real-world environment by seamlessly overlaying digital information, creating an interactive and immersive experience (Partarakis & Zabulis, 2024). Its integration into educational settings has been widely celebrated for its potential to deepen engagement and foster understanding, especially for concepts that are inherently complex or abstract t (Maker et al., 2021). However, some studies also highlight challenges related to technological limitations, development costs, and the need for adequate teacher training to fully harness AR's potential, indicating that its positive impacts are not uniformly realized without careful implementation. At its core, the adoption of AR in education aligns with fundamental shifts in pedagogical philosophy, moving beyond purely transmissive models towards more dynamic, learner-centered paradigms grounded in prominent "grand theories" of learning, offering robust frameworks to understand how AR can enhance the learning process Constructivism, a foundational learning theory championed by theorists such as Khadidja (2020), posits that learners actively construct their understanding and knowledge of the world through experiencing things and reflecting on those experiences. AR, with its interactive, exploratory, and manipulative nature, provides rich, simulated environments that are ideal for such active knowledge construction. By allowing learners to interact directly with virtual objects in their physical space, AR facilitates a deeper, more personal engagement with content, fostering genuine discovery and problem-solving rather than rote memorization (Koumpouros, 2024; Papanastasiou et al., 2019; Sharmila, 2024). This makes it particularly pertinent for English Language Learning (ELL), as it enables learners to construct meaning in an authentic, contextualized manner, moving beyond static textbook examples to real-time linguistic application.

Furthermore, from a Cognitivist perspective, which broadly examines mental processes like perception, memory, and problem-solving, AR offers novel ways to present information, potentially reducing cognitive load and enhancing information processing. By making abstract concepts concrete and visual, AR can optimize the way information is encoded, stored, and retrieved in memory, thereby facilitating deeper learning and understanding (Makhataeva et al., 2023). For ELL, this is crucial for visualizing grammatical structures, understanding semantic nuances through interactive visual cues, and improving vocabulary acquisition by presenting words in dynamic, memorable contexts. However, some research suggests that poorly designed AR interfaces can conversely increase cognitive load, highlighting the importance of intuitive and purposeful design (Gonnermann-Müller & Krüger, 2025).The Sociocultural Theory of Learning, primarily attributed to (Babakr et al., 2019), emphasizes the crucial role of social interaction and cultural tools in cognitive development. While AR can be utilized for individual learning, it also holds immense potential to foster collaborative learning experiences. By enabling

shared virtual overlays in a common physical space, AR can make abstract concepts tangible and discussible among peers, thus serving as a powerful cultural tool that mediates learning through social negotiation and shared understanding (Ahmad et al., 2020). This aligns perfectly with the idea that language learning is a deeply social process, where interaction and negotiation of meaning within a cultural context are paramount.

Mobile AR in English Language Learning (ELL)

The application of Mobile AR in English Language Learning (ELL) presents unique advantages, addressing several common challenges faced by language learners. For vocabulary acquisition, Mobile AR allows for the contextualized visualization of words, linking abstract terms to tangible 3D objects or scenes (Nikolarakis & Koutsabasis, 2024; Suzuki et al., 2020). This direct connection between the English word and its visual representation reinforces STEM (Hallström & Schönborn, 2019), suggesting that information processed through both verbal and visual channels is more effectively encoded and retrieved. Similarly, grammar concepts, often perceived as dry or complex, can be made more intuitive through interactive AR scenarios that demonstrate grammatical structures in real-time usage (Draxler et al., 2020). Beyond cognitive aspects, Mobile AR significantly impacts affective factors in language learning. The immersive quality of Mobile AR environments can reduce language anxiety by providing a low-stakes, engaging space for practice (Wu et al., 2025). This increased sense of autonomy and competence within the Mobile AR environment aligns with (Ryan & Deci, 2020), fostering intrinsic motivation for language learning. Furthermore, the game-like challenges and immediate feedback offered by Mobile AR applications can induce a state of "flow" (Tan, 2024; Yin, 2024), where learners become fully absorbed in the task, leading to enhanced concentration and enjoyment, often without consciously realizing they are studying for extended periods. The ability to customize content, such as incorporating culturally relevant elements or major-specific terminology, also strengthens the practical utility of English, consistent with (Yan et al., 2024), which emphasizes learning within authentic and personally relevant contexts.

Despite these compelling advantages and promising initial findings, the literature on Mobile AR in ELL still reveals significant gaps and areas requiring further investigation. While numerous studies highlight potential benefits in vocabulary acquisition, grammar comprehension, and affective domains, there remains a critical need for more rigorous, long-term empirical studies to substantiate these short-term gains and demonstrate sustained improvements in language proficiency. Comparative research that precisely delineates Mobile AR's efficacy against traditional teaching methods or other technology-enhanced approaches, particularly across diverse linguistic and cultural backgrounds, is still limited. Furthermore, although engagement and motivation are frequently cited as benefits, the nuanced psychological mechanisms underpinning these effects in varied learner populations require deeper qualitative and quantitative exploration.

Mobile AR Implementation in Education

Despite its promising potential, the widespread adoption of mobile AR in educational settings is not without its challenges. Technical hurdles represent a significant barrier, including issues related to device compatibility, application stability, and reliable network connectivity (Ahmed et al., 2024). Students and educators may encounter difficulties with initial setup, frequent crashes, or slow performance, which can impede the learning process and lead to frustration (Vega et al., 2025). Beyond hardware and software, pedagogical challenges also exist. Educators require adequate training to effectively integrate AR tools into their curriculum and to design engaging, pedagogically sound Mobile AR-enhanced lessons. Content creation for Mobile AR can also be resource-intensive, demanding specialized skills and significant time investment (Dhaas, 2024; Nikimaleki & Rahimi, 2022). Furthermore, issues of accessibility and equitable access to necessary devices and internet infrastructure must be considered to prevent exacerbating existing digital divides. These practical limitations highlight the need for a comprehensive understanding that goes beyond theoretical benefits to address the realities of implementation.

Despite the compelling theoretical alignment and promising preliminary findings regarding Mobile AR's potential in education, particularly for English language learning, the existing literature often provides a largely descriptive overview rather than a critical, nuanced examination of its efficacy. Specifically, there remains a significant gap in understanding how and why Mobile AR interventions precisely foster learning gains, enhance engagement, and impact affective factors, especially within diverse and often resource-constrained environments such as developing countries. Long-term empirical studies demonstrating sustained improvements in language proficiency, alongside comprehensive comparative analyses against traditional methods or other technological approaches, are notably scarce. Moreover, the intricate psychological mechanisms underpinning these effects across varied learner populations require deeper qualitative and quantitative exploration, while practical implementation challenges including technical feasibility, content localization, and adequate teacher training still lack consistent, evidence-based solutions in the current discourse. This study directly addresses these critical research gaps by providing a robust, nuanced, and humanized understanding of Mobile AR's transformative potential within specific contexts.

METHOD

Research Design and Context

A convergent parallel mixed-methods design was utilized in this study, aligning with the recommendations of Creswell & Clark, Plano (2018) for studies seeking to comprehensively understand complex phenomena by combining different data types. his particular design was chosen because it allows for the simultaneous collection and analysis of both quantitative and qualitative data, with the subsequent integration of these findings to

provide a more holistic and nuanced understanding of the research problem. Unlike purely quantitative or qualitative studies, or sequential mixed-methods designs, the convergent parallel approach offers critical advantages for Mobile AR research in English Language Learning (ELL). It addresses the multifaceted nature of learning by effectively measuring tangible outcomes like vocabulary acquisition and grammar comprehension (the "what works" from quantitative data) while simultaneously delving into the subjective experiences, motivations, and challenges faced by learners (the "how and why it works" from qualitative insights). The power of this design lies in the integration phase, where quantitative and qualitative data are independently analyzed and then directly compared and combined to either corroborate, elaborate, or challenge findings from the other dataset. For instance, a statistically significant improvement in vocabulary from quantitative analysis could be explained and enriched by qualitative reports detailing how learners' increased engagement and reduced anxiety within the AR environment fostered better retention. Conversely, if quantitative results showed minimal improvement, qualitative data might reveal underlying reasons such as technical glitches, lack of intuitive design, or insufficient teacher training. This robust integration facilitates triangulation, enhancing the overall validity and credibility of the research conclusions by cross-validating diverse data sources, and provides crucial insights for refining AR applications and ensuring their effective and equitable integration into diverse educational settings.

Participants

This study was conducted at Universitas Borneo Tarakan, Indonesia, during the academic year 2024-2025. The participants in this study consisted of 173 students (N=173), whose English language proficiency was assessed. These students were drawn from various academic departments, including Mathematics, Agrotechnology, Elementary School Teacher Education, and Indonesian Language Education. The selection of participants from diverse departmental backgrounds was purposively made to explore a broader spectrum of learning experiences and to assess the AR program's adaptability across different academic contexts, as suggested by research emphasizing the importance of context in learning ((Lohr, 2021). Participation in the study was voluntary, and informed consent was obtained from all subjects prior to their involvement, adhering to ethical guidelines for human subjects research.

To complement the quantitative findings and gain a deeper understanding of the learning process, a diverse subsample of 30 students was purposively selected from the larger group of 173 for semi-structured interviews. This subsample included approximately 5-8 students from each of the participating academic departments, ensuring representation across various disciplines. The selection criteria for these qualitative participants focused on capturing a range of English proficiency levels (assessed via the initial assessment), varying levels of engagement with the AR program (observed during classroom activities), and willingness to share detailed experiences. This strategic selection allowed for the exploration

of rich, context-specific insights into how Mobile AR influenced individual learning trajectories, perceived benefits, and encountered challenges, thereby providing the 'how' and 'why' that informed the quantitative 'what'. Additionally, classroom observations were conducted in two representative classes (one from a STEM-related department and one from a humanities-related department) to provide contextual data on in-situ AR usage and student interactions.

Intervention and Materials

The core intervention of this study was a Mobile Augmented Reality (AR)-based English learning program. This program was meticulously designed to enhance English language proficiency across three key domains: overall English achievement, vocabulary acquisition, and grammar comprehension. The design of the Mobile AR program was theoretically informed, leveraging visual elements such as 3D models and animations to present abstract English concepts and vocabulary in an interactive and engaging manner. This approach directly aligns with Paivio's Dual-Coding Theory, which posits that information is better retained when presented in both verbal and visual forms (Paivio & Clark, 2006). Furthermore, content within the program was customized to align with specific departmental curricula, aiming to demonstrate the practical necessity of English within each student's major, a pedagogical choice consistent with Situated Learning Theory, emphasizing learning in authentic and relevant contexts.

The Mobile AR application featured interactive vocabulary builders that overlaid definitions and usage examples onto real-world objects scanned by the device's camera, as well as grammar challenges that visualized sentence structures in 3D, allowing students to manipulate elements to form grammatically correct sentences. Typical activities included scavenger hunts for context-specific vocabulary, interactive dialogues with virtual characters, and gamified grammar exercises with immediate visual feedback. The intervention spanned 12 weeks, during which students were required to engage with the application for at least 60-90 minutes per week, typically broken into 3-4 sessions. This was supplemented by accompanying face-to-face learning sessions, held once a week for 90 minutes, where instructors facilitated discussions, clarified concepts introduced in the AR app, and addressed any difficulties.

The primary equipment utilized by the participants was their personal mobile devices, on which the Mobile AR application was installed. While the intervention aimed for broad accessibility, the study acknowledged and addressed practical implementation challenges identified in previous research (Hamilton & Finley, 2019). Specifically, some initial technical challenges related to device compatibility and application stability were reported by a minority of students, particularly those with older phone models. Internet connectivity was also a crucial resource for accessing the AR program and was sometimes a source of frustration due to instability. To mitigate these issues and ensure a smooth learning experience, continuous instructor support was systematically provided.

Data collection

Data collection was systematically conducted in two distinct yet complementary phases: quantitative and qualitative, ensuring a comprehensive understanding of the intervention's impact and the students' experiences. Quantitative data were gathered through standardized pre- and post-intervention assessments administered to all participants. These assessments measured students' proficiency in three specific areas: Overall English Achievement, Vocabulary Achievement, and Grammar Achievement. To ensure the robust validity and reliability of these measures, the assessment instruments were rigorously developed by a team of experienced English language educators and psychometricians. They were designed to align with established English language proficiency frameworks and the specific learning objectives of the Mobile AR program.

Each test comprised a total of 120 questions, distributed as follows: 50 multiple-choice questions for Overall English Achievement (covering reading comprehension and general usage), 40 fill-in-the-blank and matching questions for Vocabulary Achievement, and 30 error identification and sentence correction questions for Grammar Achievement. Prior to their full implementation in this study, the instruments underwent a pilot test with a comparable group of students to assess their clarity, appropriateness, and psychometric properties. Reliability analysis, using Cronbach's Alpha, yielded coefficients above 0.85 for all sub-sections, indicating high internal consistency. The tests were rigorously administered consistently to ensure the comparability of results, a critical aspect of quasi-experimental designs. All responses were automatically collected via Google Forms, which facilitated efficient data management and minimized manual error. The pre-test was administered prior to the commencement of the mobile AR learning program, and the post-test was conducted upon its completion, allowing for the precise measurement of learning gains attributable to the intervention. Qualitative data were systematically collected to explore the students' experiences, perceptions, and feedback regarding the AR-based English learning program, providing the rich, in-depth insights that quantitative data alone cannot capture (Wedyan et al., 2022). This involved two primary methods: semi-structured interviews and direct observations. Interviews were conducted with a subset of students from various departments, allowing for in-depth discussions about their engagement, perceived benefits, and any challenges encountered during their interaction with the AR program. The semi-structured format allowed for flexibility in exploring emerging themes while ensuring coverage of key research questions. Observations were carried out during the learning sessions to capture immediate feedback, non-verbal cues, and contextual factors that influenced the learning process in real-time.

Data Analysis

Both quantitative and qualitative data were rigorously analyzed to address the research objectives, with methods chosen to maximize the validity and interpretability of the findings. Quantitative data obtained from the pre- and post-tests were analyzed using the Statistical

Package for the Social Sciences (SPSS) software. Paired Samples t-tests were performed to determine the statistical significance of the differences between pre- and post-intervention scores for Overall English Achievement, Vocabulary Achievement, and Grammar Achievement. This statistical test is widely accepted for comparing means from the same group under two different conditions. Effect sizes were calculated using Cohen's d to quantify the practical significance of the observed gains, providing an indication of the magnitude of the intervention's impact beyond mere statistical significance. Additionally, normalized gain (N-gain) values were computed to assess the learning effectiveness, indicating the proportion of the maximum possible gain that was actually achieved by the students, a common metric in educational research for evaluating learning improvement. A significance level of $p < 0.001$ was set for all statistical tests to ensure the robustness of the findings and minimize the chance of Type I errors.

Qualitative data, derived from student interviews and observations, were subjected to thematic analysis, a widely recognized method for identifying, analyzing, and reporting patterns (themes) within data (Braun & Clarke, 2019). This involved systematically reviewing transcripts and field notes to identify recurring themes, patterns, and categories related to the students' experiences with the AR program. The analysis process included familiarization with the data, generation of initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final report. All qualitative data coding and thematic development were primarily conducted by the lead researcher to ensure consistency in interpretation. To enhance the trustworthiness and validity of the qualitative findings, several measures were employed. Firstly, the qualitative findings were continuously triangulated with the quantitative results to seek convergence or divergence, providing a holistic understanding of the phenomena. Secondly, "member checking" was performed with a subset of interview participants, where preliminary themes and interpretations were presented back to them for validation and clarification, ensuring that the researcher's understanding aligned with their lived experiences. This qualitative analysis, facilitated by the use of NVivo software for efficient data organization and management, allowed for a detailed exploration of students' perceptions, immediate feedback, and the contextual factors that influenced their learning, providing a deeper, more humanized understanding that enriched and contextualized the statistical findings.

FINDINGS

This study investigates the effectiveness of a Mobile Augmented Reality (AR)-based English learning program through a comprehensive mixed-methods approach, integrating both quantitative and qualitative data. The primary objective was to assess the impact of AR on students' English language achievement and to gain an in-depth understanding of their learning experiences within this innovative environment. The quantitative analysis focused on measuring improvements in overall English, vocabulary, and grammar proficiency. At the same time, qualitative data, systematically gathered through student interviews and

observations, aimed to explore the nuanced perceptions, immediate feedback, and contextual factors influencing learning.

English Learning Achievement

Table 1.
Pre- and post-intervention

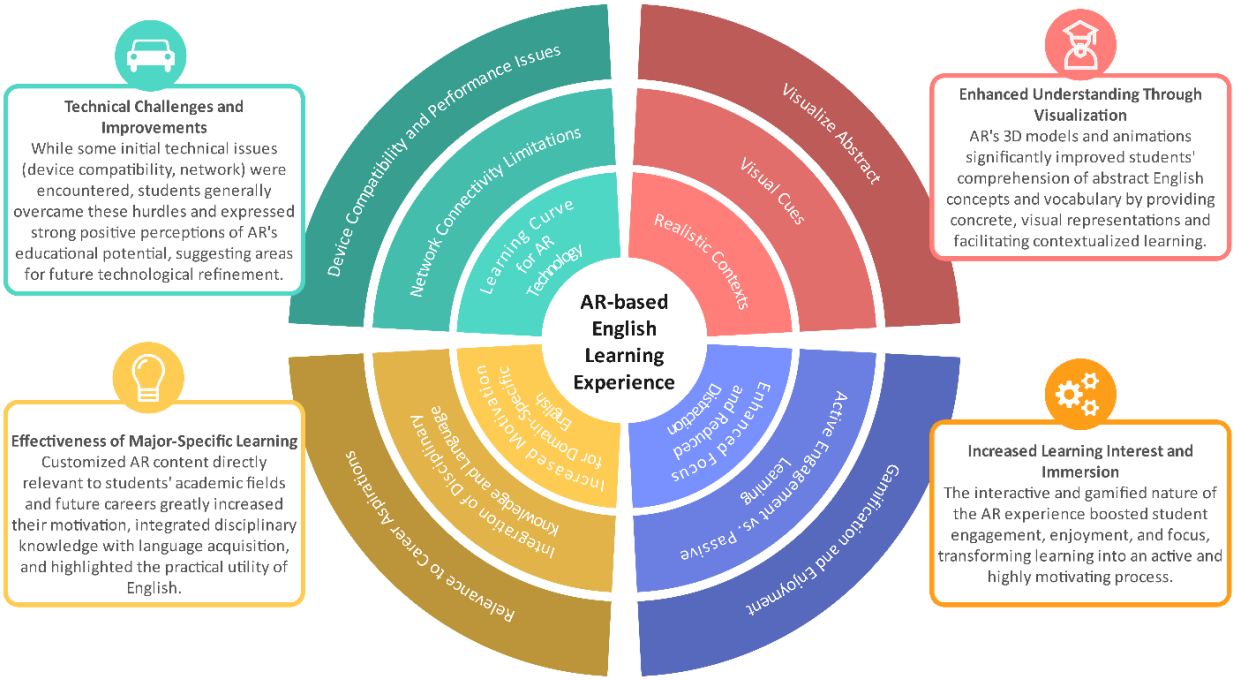
Measure	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Paired Samples t-test	Interpretation	N-gain Value
Overall English Achievement	60.00 ± 8.50	78.00 ± 7.20	t (172) = 25.00 p < 0.001 Cohen's d = 2.10	Significant	0.75 (High)
Vocabulary Achievement	55.00 ± 9.00	75.00 ± 8.00	t (172) = 22.50 p < 0.001 Cohen's d = 1.95	Significant	0.74 (High)
Grammar Achievement	58.00 ± 8.80	77.00 ± 7.50	t (172) = 23.80 p < 0.001, Cohen's d = 2.05	Significant	0.75 (High)

Based on Table 1, the Pair samples t-test indicates that the improvements are statistically significant in each of the three domains that were measured. To be precise, the overall rate of English Achievement had an influential mean difference of 60.00 (SD = 8.50) pre-test and 78.00 (SD = 7.20) post-test (t (172) 25.00, p < 0.001). Such gain is further supported by a considerable effect size (Cohen s d = 2.10) and an N-gain equal to 0.75 as per a high level of learning gain. Equally, Vocabulary Achievement showed a distinct increase between a pre-test mean (SD) value of 55.00 (SD = 9.00) and a post-test mean (SD) value of 75.00 (SD = 8.00) (t(172) = 22.50, p < 0.001) with a massive effect size (Cohen =1.95) and a large N-gain of 0.74. Moreover, Grammar Achievement gained a considerably considerable significance as well as 77.00 points (SD = 7.50) increased the average score during the range of 58.00 points (SD = 8.80) (t(172) = 23.80, p < 0.001) and was considered to be a considerable effect size (Cohen s d = 2.05) as well as a high N-gain of 0.75. The negligible variability in all measures in terms of statistical significance (p < 0.001) and their effect size (Cohen s > 1.95), as well as the 'High' N-gain ratings, altogether support the view of the tremendous and practically significant positive effect of the mobile AR-based intervention conducted on English language proficiency of the students.

Exploring Student Experience with Mobile AR-Based Learning

A detailed view of the student experience with the mobile Augmented Reality (AR)-based English learning program was obtained by collecting the following data that was systematically gathered through interviews with students and observations. Such a method implied a possibility to investigate subtle perceptions and immediate feedback, supplementing the results by shedding light on the mechanisms involved and situational circumstances that condition learning.

Figure 1
AR-based English Learning Experiences



(Source: generated from Wondershare EdrawMax)

Enhanced Understanding Through Visualization

The visual nature of AR, particularly through 3D models and animations, was consistently highlighted by students as a key factor in enhancing their comprehension of abstract English concepts and vocabulary. Students across various departments found that the ability to visualize complex information translated directly into clearer understanding of the associated English terminology. For instance, a student from the Mathematics Department articulated how seeing geometric shapes in 3D facilitated understanding of English terms, stating, "Before, understanding geometric terms in English was just memorizing definitions. But with the AR models, I could actually see the shapes and angles in 3D, and the English terms just clicked. It made abstract concepts so much clearer." *(Student 1, Mathematics Department)*. Similarly, an Agrotechnology student found that "Learning about 'hydroponics' or 'precision farming' in English was difficult from a textbook. But when the Mobile AR app showed us the 3D models of the systems and labeled the parts in English, it was like a lightbulb moment. I could visualize everything." *(Student 2, Agrotechnology Department)*. This visual aid was also beneficial for Elementary School Teacher Education students, who noted, "For young learners, visualizing vocabulary is key. The 3D models of animals or objects in the AR app made it easy to connect the English word to the real thing,

which is much better than just flashcards." *(Student 3, Elementary School Teacher Education Department)*, emphasizing the clarity provided by the visual representations.

Increased Learning Interest and Immersion

Students frequently reported a significant increase in their learning interest and immersion due to the interactive and captivating nature of the Mobile AR technology. This enhanced engagement translated into sustained concentration and enjoyment, thereby supporting the high engagement and motivation levels observed in the quantitative findings. An Indonesian Language Education student's remark exemplified this sentiment: "I usually get bored with English grammar exercises, but the Mobile AR app made it feel like a game... It was so engaging that I didn't even realize I was studying for an hour." *(Student 4, Indonesian Language Education Department)*. The immersive quality of the Mobile AR environment was also a strong motivator, with a Mathematics student describing it as "amazing... It felt like the English lesson was happening right in my room. This made me want to keep exploring and learning more, unlike traditional classes where my attention often drifts." *(Student 5, Mathematics Department)*. Furthermore, the integration of interactive elements, such as quizzes, transformed the learning experience into a "challenge" rather than a mere "test," as an Agrotechnology student noted, fostering greater motivation and faster learning. "The interactive quizzes within the Mobile AR environment were really fun. It didn't feel like a test; it felt like a challenge, and that motivated me to try harder and learn the vocabulary faster." *(Student 6, Agrotechnology Department)*.

Effectiveness of Major-Specific Learning

The customization of content to align with each department's specific curriculum proved to be highly effective, fostering a deeper realization among students of the practical necessity of English and enabling them to integrate their specialized knowledge with language acquisition. An Elementary School Teacher Education student highlighted the direct relevance, stating, "When we learned English vocabulary for classroom management or child development through AR, it felt directly relevant to my future profession. It wasn't just generic English; it was English I would actually use as a teacher." *(Student 7, Elementary School Teacher Education Department)*. Similarly, a Mathematics student found that "Learning English about calculus or algebra using Mobile AR was fantastic. It showed me how English is essential for advanced studies and research in my field. It connected the dots between my major and the language." *(Student 8, Mathematics Department).* An Indonesian Language Education student articulated the empowering aspect of culturally relevant content, observing, "The Mobile AR stories with Indonesian cultural elements, told in English, were fascinating. It made me think about how I could use English to share our culture with the world, which felt very empowering." *(Student 9, Indonesian Language Education Department)*.

Technical Challenges and Improvements

While the overall reception of the Mobile AR technology was highly positive, some students initially encountered technical challenges, primarily related to device compatibility, application stability, and network connectivity. An Agrotechnology student, for instance, reported, "At first, I had some trouble with the app crashing on my older phone, and the internet connection was sometimes unstable, which was frustrating." *(Student 10, Agrotechnology Department)*. A Mathematics student also noted that "Setting up the Mobile AR environment took a little time and patience initially. There were a few glitches, but the instructors helped us, and after the first week, it was mostly smooth sailing. The benefits definitely outweighed these minor issues." *(Student 11, Mathematics Department)*. Despite these initial hurdles, which were largely overcome after an adaptation period and instructor support, students consistently expressed a high appreciation for the potential of Mobile AR technology in education, with one Elementary School Teacher Education student concluding, "I think for AR to be fully adopted, the technology needs to be more accessible and robust across different devices. However, the potential for engaging learning is huge, and I hope it becomes more common." *(Student 12, Elementary School Teacher Education Department)*.

DISCUSSION

The findings of this study provide compelling evidence regarding the significant positive impact of a Mobile Augmented Reality (AR)-based intervention on students' English language proficiency and their overall learning experience. The integration of quantitative and qualitative data offers a nuanced understanding of how Mobile AR contributes to learning gains and shapes student perceptions. Substantial improvements were observed across all measured aspects of English language proficiency, including overall English achievement, vocabulary acquisition, and grammar comprehension. The quantitative analysis revealed statistically significant gains in post-test scores compared to pre-test scores for all three measures ($p < 0.001$), accompanied by remarkably large effect sizes (Cohen's $d > 1.95$) and high N-gain values (0.74-0.75). These results indicate not merely a statistical difference but a practically significant and tremendous positive effect of the Mobile AR-based program. This finding is consistent with a growing body of literature that demonstrates Mobile AR's effectiveness in enhancing academic achievement in various educational contexts (e.g., Cai et al., 2019; Chen, 2019; Chin et al., 2019). While alternative explanations such as the Hawthorne effect could be considered, the consistently high effect sizes across multiple language domains suggest a genuine and robust impact attributable to the Mobile AR intervention itself.

Qualitative data further illuminated the mechanisms underlying these quantitative gains, particularly highlighting the role of visualization in comprehension. Students consistently reported that the visual nature of Mobile AR, specifically through 3D models and animations, significantly enhanced their understanding of abstract English concepts and vocabulary, making complex information "click" into place. This observation strongly supports Paivio's Dual-Coding Theory, which posits that information processed through

both verbal and visual channels is more effectively encoded and retrieved. Previous research on multimedia learning similarly underscores the benefits of visual aids in reducing cognitive load and improving comprehension (Mayer, 2017). The ability to visualize concepts like geometric shapes or scientific processes directly translated into a clearer grasp of associated English terminology, a benefit that transcended specific academic disciplines.

Furthermore, the Mobile AR intervention was found to significantly increase students' learning interest and immersion. The interactive and captivating nature of the AR technology transformed learning into a more engaging and enjoyable experience, often likened to a game rather than a test. This enhanced engagement translated into sustained concentration, with students reporting prolonged study periods without feeling bored, aligning well with Barkley & Major (2020) , where optimal experience is achieved through deep immersion in an activity. The interactive quizzes, in particular, reframed learning as a "challenge," fostering greater motivation and faster learning. This motivational aspect is also congruent with Reeve, J., Ryan, R. M., & Deci (2018), as the AR environment provided elements of autonomy and competence, thereby fostering intrinsic motivation for learning.

The customization of content to align with each department's specific curriculum proved to be highly effective, fostering a deeper realization among students of the practical necessity of English. Students across diverse majors, from Elementary School Teacher Education to Mathematics and Indonesian Language Education, articulated how the major-specific content made English directly relevant to their future professions and advanced studies. This finding strongly supports Lave and Wenger's Situated Learning Theory, which emphasizes that learning is most effective when it occurs within authentic and personally relevant contexts. By connecting English language acquisition directly to their specialized knowledge, the AR program effectively bridged the gap between academic learning and real-world application, empowering students to see English as a vital tool for their chosen fields.

Despite the overwhelmingly positive reception, the study acknowledged initial technical challenges encountered by some students, primarily related to device compatibility, application stability, and network connectivity. These issues, such as app crashing on older phones or unstable internet connections, are consistent with common implementation hurdles identified in broader literature on educational technology adoption (Ahmad et al., 2020; Granić, 2022; Lucas, 2020). However, it was noted that these initial difficulties were largely overcome after an adaptation period and with consistent instructor support. The students' perseverance and the perceived benefits of the Mobile AR technology ultimately outweighed these minor issues, reinforcing the potential of Mobile AR despite its current technical limitations. While this study demonstrated a significant positive effect, a limitation lies in its quasi-experimental design, which did not include a true control group, making it difficult to definitively rule out all alternative explanations for the observed gains.

Additionally, the qualitative data relied on self-reported perceptions, which, while valuable, may be subject to social desirability bias.

Based on these compelling results, several practical actions and suggestions can be offered. For educators and curriculum designers, it is strongly recommended to consider integrating Mobile AR tools that leverage 3D visualization and offer interactive, context-specific content, as these features were found to be particularly impactful. Investment in robust instructor training on Mobile AR pedagogy is crucial to maximize the technology's potential. Mobile AR developers are encouraged to prioritize user-friendly interfaces and robust application stability across diverse devices to minimize initial technical frustrations while continuing to design content that directly supports established learning principles. Ultimately, this study advises the broader educational community to embrace Mobile AR as a powerful, human-centered tool for creating dynamic, engaging, and highly effective language learning experiences while pragmatically planning for and addressing the practical challenges inherent in technological adoption.

Future research should explore long-term learning gains and sustained engagement with Mobile AR. Controlled studies with true control groups could better isolate its effects, while examining specific AR features and their integration into curricula would offer deeper insights. Investigating best practices for instructor training and developing scalable, cost-effective AR solutions would further support its broader adoption in language education.

CONCLUSION

This study is a comprehensive investigation to assess the effectiveness of a Mobile Augmented Reality (AR) -based English learning program and to gain an in-depth understanding of students' experiences within this innovative environment. The findings highlight the profound positive impact of the Mobile AR intervention on English language proficiency. Significant and practically meaningful gains were observed across overall English achievement, vocabulary acquisition, and grammar comprehension, affirming Mobile AR's capacity to enhance learning outcomes substantially. Beyond these measurable improvements, the originality of this work lies in its human-centered exploration of how and why Mobile AR is effective. Qualitative findings show that Mobile AR's visual features help students grasp abstract concepts, supporting dual-coding theory, while customized content enhances relevance through situated learning. Beyond proving its effectiveness, the study uncovers the psychological and pedagogical factors behind Mobile AR's impact. Despite initial technical challenges, students reported strong benefits, indicating high acceptance and adaptability. The study confirms that Mobile AR is a highly effective approach for improving language proficiency and deepening engagement and understanding.

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CONFLICT OF INTEREST

No conflict of interest reported by the author(s)

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ABOUT THE AUTHORS

Author's Biography			
Name	*Nofvia De Vega*		
Affiliation	*Universitas Borneo Tarakan*		
Email	*nofviadevega@borneo.ac.id*	Scopus ID	*57222573635*
Google Scholar	*Click Here*	WoS ID	*AAK-7753-2021*
Research Interest	*She is one of English Education Department lecturers at Universitas Borneo Tarakan. Her research focuses on Teaching English and information and communication technology (ICT) in Education. Listening and learning media are her major skill and competency in teaching and learning process.*		

Author's Biography			
Name	*Syarifa Rafiqa*		
Affiliation	*Universitas Borneo Tarakan*		
Email	*rafiqa@borneo.ac.id*	Scopus ID	*57277163000*
Google Scholar	*Click Here*	WoS ID	-
Research Interest	*She has been a lecturer in the English Education Department at the University of Borneo Tarakan since 2010, and was, until recently, the head of the language center at the University of Borneo Tarakan. She has a high interest in the studies of English language learning, applied linguistics, and ICT in English language teaching and learning.*		