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Mixing Augmented and Virtual Reality for Low-Proficiency Learners in Rural Areas: A Single-Group Repeated-Measures Study of Vocabulary Growth

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ABSTRACT

In many schools, the conventional resources used to teach English are often inadequate for learners with low-proficiency levels. This challenge is heightened for rural students who struggle with second language acquisition due to limited exposure and support. However, incorporating Augmented Reality (AR) and Virtual Reality (VR) can help overcome these barriers by immersing learners in interactive 3D environments that support visual and experiential learning. Engaging with digital objects and simulations enables students to process information more deeply through visual and hands-on interaction. With this in mind, the present research implemented Mobile Augmented and Virtual Reality (MAVR) technology, which was developed on the Android platform, to support vocabulary development among low-proficiency ESL learners. The MAVR application was developed using the ADDIE instructional design framework to ensure pedagogical effectiveness. A single-group repeated measures longitudinal quasi-experimental design involving 12 measurement points was employed to monitor changes in vocabulary acquisition among 41 participants. Analysis using one-way repeated measures ANOVA revealed a significant improvement in vocabulary scores over time. The findings suggest that MAVR-based learning has the potential to enrich English language instruction by making vocabulary learning more dynamic, accessible, and meaningful for low-proficiency learners.

Keywords: rural schools, low-proficiency learners, augmented reality, virtual reality

INTRODUCTION

Nowadays, it has become a necessity to use multimedia or computer aided instruction models for scientific concepts. Through research in the application of 3D animation learning, Tepla, Teply and Smejkal (2022) discovered that 3D models and animation improved learners' learning outcomes of science students in Biology, Chemistry and Geology compared to static visualization. It was found that the students understood better as it enables the learners to visualize sciences subjects which are mostly abstracts and incorporate a new piece of information into long term memory. It can be implied that by providing teaching materials, such as 2D and 3D animation, a simulation-based e-learning model is helpful for improving the learning effectiveness of the concepts of basic ideas in sciences. They enhance student engagement, simplify abstract concepts with 3D visualization and simulation and provide hands-on training in a safe environment as it enables students to conduct experiments with costly equipment or hazardous chemicals virtually, while AR can guide them through intricate procedures step by step (Javaid et al., 2024:2).

In brief, current research on simulation-based learning indicates that teaching aided by interactive 2D or 3D models such as AR and VR can significantly help learners understand spatial concepts in sciences. Even though most previous research has focused on Sciences subject, this study tried to implement AR and VR in a different context that is the English language learning classroom which is very constrained now in terms of advancement in simulation-based learning material especially for low-proficiency learners. It is hoped that this kind of simulation-based e-learning system that is Mobile Augmented Virtual Reality (MAVR) may help low-proficiency learners not just gain interest but to obtain more knowledge in understanding and using vocabulary in English language learning. This study focused on vocabulary learning and progress which would be learnt via Mobile Augmented-Virtual Reality (MAVR) apps created in this study known as Hunting with e-Language.

LITERATURE REVIEW

The integration of immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR) into teaching and learning has received increased attention in recent years, particularly in STEM education, where these tools have been shown to enhance learners' conceptual understanding and engagement (Teplá et al., 2022; Javaid et al., 2024). However, despite the fast development in AR/VR research, applications of these technologies in the English as a Second Language (ESL) context especially in vocabulary development for young, low-proficiency learners remain underexplored. This shows an important gap in the literature where AR/VR has yet to be applied to scaffold abstract language concepts through experiential learning for underprivileged ESL learners.

Current studies on AR-supported language learning have showed advantages in contextualizing vocabulary in authentic and interactive environments (e.g., Chung, Lee & Chen, 2019; Liu, Tsai & Yin, 2021). However, these studies largely conducted in urban or well-equipped classroom settings where learners have reliable access to devices and facilities. As pointed out by Moaz Nair (2025) schools in urban areas generally enjoy better infrastructure, resources, and technological support, creating a more engaging and conducive environment for English language learning. In contrast, limited research has looked at the techno-pedagogical challenges setting like in rural ESL classrooms, where there is limited exposure to English and limited access to technological teaching aids. This has resulted in chronic underperformance among these students, for example, 42% of rural students who scored below passing grades in SPM English in 2022 (Rowena Chua, 2024).

While experiential learning has been identified as an effective approach in second language acquisition (Knutson, 2003; Žukauskaitė, 2021), its implementation is often a challenge due to the resource-constrained environments. The use of Mobile AR/VR (MAVR) has the potential to bridge this gap by enabling learners to visualize and manipulate vocabulary in situational or game-based contexts without the physical resources or infrastructure usually needed to support such interactivity. By linking vocabulary to meaningful sensory experiences, AR/VR supports Mayer's (2005) Cognitive Theory of Multimedia Learning (CTML), which posits that learning is enhanced when visual and verbal information are presented in a way that reduces extraneous load and fosters deeper cognitive processing.

However, there remains a lack of research on how AR/VR might affect the vocabulary development over time, particularly among low-proficiency ESL learners in rural settings. The present study seeks to address this gap by employing a Mobile AR and VR intervention based on the ADDIE instructional design model to support vocabulary learning among Year 2 rural learners, and also by examining vocabulary growth over 12 time points. In doing so, this research responds to two critical needs: (1) to empirically test MAVR as a language-learning tool for underserved ESL populations, and (2) to provide evidence for more sustained, practice-based instructional design research in AR/VR environments.

Technology Integration in this study

Augmented Reality (AR) and Virtual Reality (VR) are immersive technologies that layer or simulate digital information within real-world or virtual environments. AR overlays digital media such as images, animations, or 3D models onto physical surroundings through devices equipped with cameras and processors, enabling learners to interact with enhanced representations of real objects (Azuma et al., 2011; Gutiérrez & Fernández, 2014). VR, on the other hand, creates fully virtual environments that simulate real-world contexts, allowing learners to engage in immersive, multisensory experiences.

In this study, AR and VR are used to support English vocabulary acquisition by providing visual and interactive representations of target words from the Ministry of Education's Year 2 curriculum. With AR, learners use mobile devices to scan fiducial markers and visualize animated objects (e.g., a "brush" that moves to simulate brushing hair), enabling them to associate vocabulary items with meaningful actions and contexts. The VR component complements this with 360-degree scenes where learners navigate simulated spaces (for example, a kitchen or classroom) and identify vocabulary in context which promotes deeper retention through experiential learning.

This intentional design aligns with Mayer's (2005) Cognitive Theory of Multimedia Learning, which emphasizes that learning is strengthened when verbal information is paired with relevant pictorial cues through dual channels. By connecting vocabulary to dynamic visual and spatial cues, the MAVR experience fosters cognitive integration and reduces extraneous load for low-proficiency learners.

Due to limited access to personal smartphones among rural learners, the intervention was designed to run through a WiFi-enabled projector, displaying AR/VR content as shared experiences. This approach ensured equitable access and encouraged collaborative learning, making the intervention feasible and inclusive despite technological barriers.

The integration of MAVR in this study thus serves as both a pedagogical innovation and a practical solution for engaging low-proficiency ESL learners in rural settings. By blending visual immersion with language instruction, the technology addresses common challenges such as limited linguistic exposure, low motivation, and scarce instructional resources.

Theoretical Framework

This study is anchored in the Cognitive Theory of Multimedia Learning (CTML), which highlights how people process information through multiple sensory channels. The theory rests on three key principles: (1) individuals handle visual–pictorial and verbal–auditory information through distinct mental pathways; (2) each channel has a limited capacity for processing input; and (3) effective learning occurs when the learner is actively engaged in constructing meaning. As outlined by Mayer (2005), genuine learning happens when learners attend to important visual and verbal cues, organize these cues into coherent mental structures, and connect them with prior knowledge to form integrated understanding.

Within this perspective, multimedia instruction is defined as the delivery of information through a blend of words and images, which may appear in print or be enhanced through digital features such as animation and video. Guided by these principles, the current research designed Mobile Augmented and Virtual Reality (MAVR) materials to create a more interactive and visually enriched learning experience for learners with limited English proficiency. The integration of realistic visual content and spatial interaction was intended to help students make concrete connections to language concepts that are often abstract in traditional instruction. Mayer (2005) also asserts that CTML remains aligned with contemporary cognitive science, offers hypotheses that can be empirically validated, and serves as a valuable foundation for designing effective multimedia learning environments.

METHODOLOGY

Research Design

This study employed a single-group repeated measures longitudinal quasi-experimental design with 12 measurement points to examine the effect of Mobile Augmented and Virtual Reality (MAVR) on the vocabulary development of low-proficiency ESL learners in rural primary schools. The design involved repeated observations of the same group over 12 time points of before, during, and after an intervention. This approach allowed for the assessment of both the level (mean score) and trend (rate of change) in performance to determine whether significant changes occur following the introduction of the intervention (Bernal, Cummins, & Gasparrini, 2017). In the context of this study, this design was chosen given the real-world school constraints and the desire to observe repeated measurements of vocabulary growth across multiple time points before and after exposure to MAVR materials.

In this study, vocabulary scores were collected over 12 consecutive time points (i.e., 12 sets). The first three points represented the baseline phase (conventional teaching), while the subsequent time points corresponded to the intervention phase, during which the intervention began with basic AR materials and later more advanced AR and VR activities were introduced progressively every two weeks as shown below;

Phase	Weeks	Learning Activities
Baseline	1-3	Conventional vocabulary instruction
Early MAVR	4-6	Basic AR activities
Middle MAVR	7-9	AR+VR contextual tasks
Advanced MAVR	10-12	Complex vocabulary tasks

The repeated measurements allowed for the examination of both immediate and sustained effects of the MAVR intervention on students' vocabulary acquisition.

This design was chosen because random assignment and a control group were not feasible in the school setting. In other words, the learners were already assigned by the school to be placed in the particular class. However, the repeated-measures structure design provides strong internal validity by controlling individual differences and observing temporal patterns, making it a robust option for classroom-based educational research (Wagner, Soumerai, Zhang, & Ross-Degnan, 2002).

Research Question

In general, this study aims to examine the effectiveness of using simulation-based instructional design that is Mobile Augmented Virtual Reality (MAVR) on vocabulary learning in English language among low-proficiency learners in rural areas. Specifically, this study seeks to answer the following research question: To what extent does Mobile Augmented and Virtual Reality (MAVR) improve vocabulary knowledge of low-proficiency primary school learners in rural areas?

Selection of participants

The study was conducted in a primary school in Selangor rural areas. The participants comprised 41 students from Year 2 (aged 8 years old). All participants were selected from an intact class and had been identified by their school as low-proficiency ESL learners based on school-based assessment and literacy screening. These assessments were administered by the school for Year 1 till Year 3 students to identify those who have difficulty in basic reading, writing and counting skills. Since the study was conducted in an existing classroom, random sampling was thus not feasible. The sample comprised 29 girls and 12 boys, all of whom had limited access to individual digital devices. These participants also came from B40 household category which refers to the low-income households in Malaysia. Due to this limitation, MAVR materials thus were delivered using a Wi-Fi enabled projector to provide an equitable access to the intervention.

Research Procedure

Intervention and Instructional Design

The MAVR learning materials were developed using the ADDIE model (Analysis, Design, Development, Implementation, Evaluation as shown in Figure 1 below), which guided the systematic creation of AR/VR experiences tailored to the learners' needs. The intervention used a researcher-designed application called *Hunting with e-Language* that enabled learners to interact with 3D animated vocabulary items through augmented markers and virtual environments. AR projections and VR scenes were used alternately, and learning content increased in complexity every two weeks from individual-word identification to object-action pairing.

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The use of Unity with Vuforia Engine allowed the development of marker-based AR triggers linked to vocabulary items from the Malaysian Ministry of Education Year 2 ESL textbook. To overcome the lack of one-to-one device access in the rural classroom, sessions were projected through a Wi-Fi-enabled projector to ensure whole-class participation and reduce access inequity.

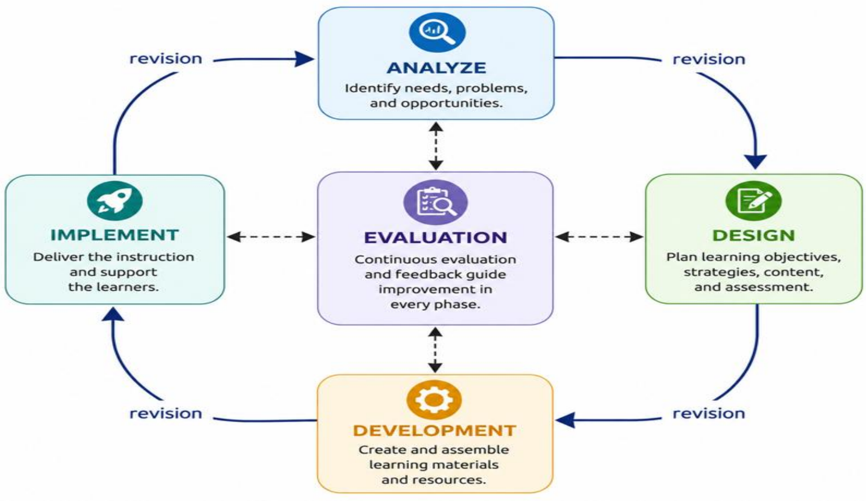


Figure 1 ADDIE Model phases

Based on these five phases, the process of this study is arranged into two main stages;

Stage 1 (Analyze Phase): Literature exploration / Phenomenon Review

In this phase, the focus was the target audience and the researcher aimed to identify the level of skills, intelligence, difficulties that the students and teachers are facing in teaching and learning process. Basically, at this stage, the researcher would spend time studying the materials and the learners' background first because the application and creation of AR materials needs to be designed carefully with respect to the user's level of knowledge.

Stage 2 (Design Phase): Developing the MAVR learning materials

In this phase, the researcher determined the goal and developed the tools to achieve the learning objectives. At this stage, the researcher basically decided the different types of media in designing the MAVR materials and teaching methods to be used. The steps of identifying and designing the AR materials can be displayed as in Figure 2 below;

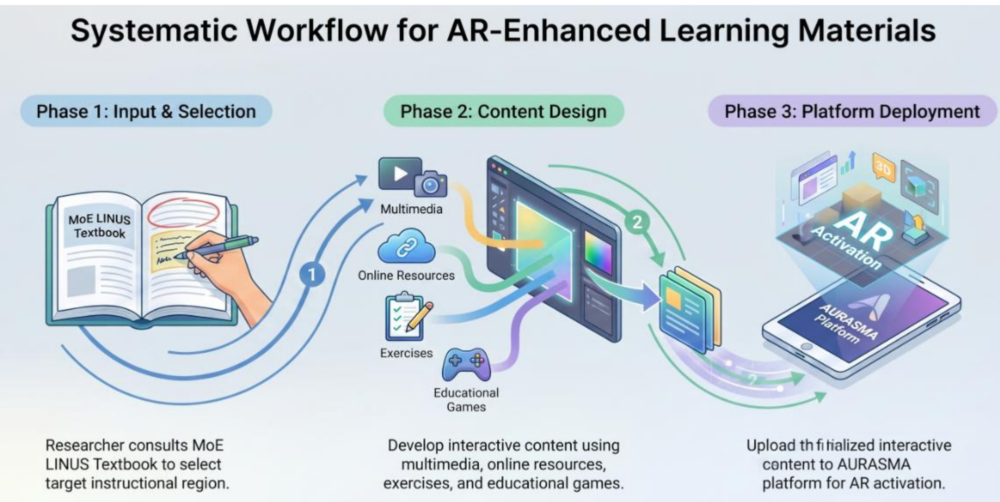


Figure 2 Designing process of augmented content for LINUS textbook (Generated using NotebookLM)

Overall, during this phase, the content of the selected materials was thoroughly analysed to identify and select suitable images and videos that aligned with the learning objectives of the study. These multimedia elements were carefully chosen to enhance learners' comprehension of vocabulary by providing clear visual and contextual representations. Once identified, the images and videos were integrated into the augmented and virtual reality environment to create markers, which served as interactive visual triggers for the learning materials. Through these markers, the static content from the textbook was transformed into dynamic and engaging digital experiences, allowing learners to visualize, interact with, and better understand the targeted vocabulary items.

Instruments

British Picture Vocabulary Scale

The vocabulary test used in this study was the British Picture Vocabulary Scale, Third Edition (BPVS III), a widely used receptive vocabulary instrument suitable for learners with limited literacy or expressive language proficiency (GL Education Group, 2018). The BPVS III is an individually administered assessment designed to measure learners' receptive vocabulary ability. In this test, the examiner reads aloud a target word, and the learner responds by selecting one picture from four options that best represents the meaning of the word. The test comprises 12 levels, which provide an estimate of the learner's vocabulary age and developmental progress. The BPVS-III was selected due to its low language-related cognitive load, allowing researchers to reliably track vocabulary understanding without requiring reading or verbal responses. Internal consistency and reliability of the BPVS-III have been well documented across multilingual learner populations. It can also be effectively used with students who have mild autism, communication difficulties, or who are learning English as an Additional Language (EAL), as the format minimizes verbal and literacy demands.

Unity + Vuforia Engine platform

In this study, Unity + Vuforia Engine platform was utilized as it allows the researchers to create, manage visual images and connect digital content such as video images (using video platform) and animation (animation platform) in books and classroom walls. All objects superimposed with MAVR creation were processed through Unity + Vuforia Engine platform making all objects alive and have their own aura.

Mobile Augmented Virtual Reality (MAVR) in this study

This application in this study focuses on Mobile Augmented Virtual Reality (MAVR) technology developed using the Android platform to enhance learning among students in primary schools especially those who struggle in learning literacy and numeracy. The programme focuses on vocabulary learning in English language classroom in which MAVR materials were developed to enrich and enliven vocabulary learning. The augmented and virtual reality application called Hunting with e-language will display models after detecting fiducial markers created and the multimedia application will present digital material and user-friendly games for the students. Overall, the learners can explore in 360-degree scenario via virtual reality experience as shown in Figure 3 below.

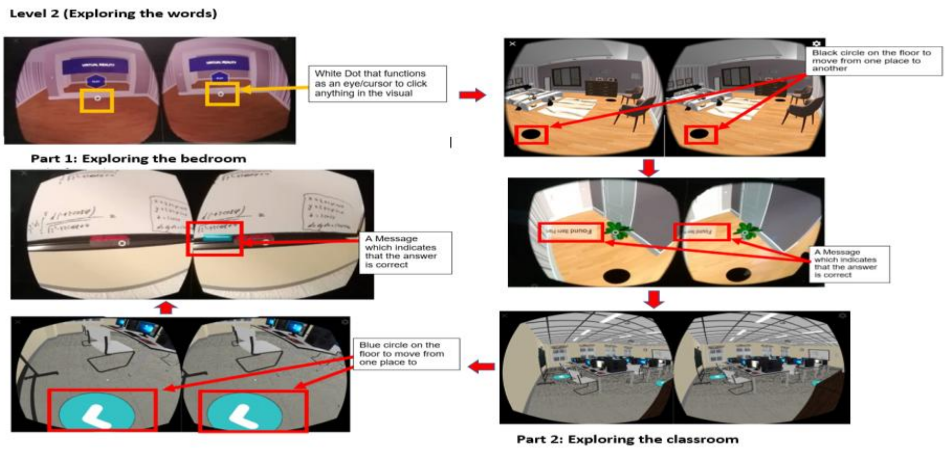


Figure 3 Screenshot of Virtual Reality Materials developed in this study

To determine whether the Mobile Augmented and Virtual Reality (MAVR) intervention produced measurable improvements in learners' vocabulary development over time, the data collected across twelve sets were subjected to a series of statistical analyses. The following section presents the results of these analyses, beginning with preliminary assumption tests before proceeding to repeated measures analyses.

Findings

This section reports the statistical outcomes of the study, which aimed to determine the effect of Mobile Augmented and Virtual Reality (MAVR) activities on the vocabulary growth of low-proficiency ESL learners in a rural primary school. Vocabulary scores were collected from the same group of 41 low-proficiency ESL learners across 12 weekly sets while AR/VR activities were introduced every two weeks (within-subjects, repeated measures). In this study, there were twelve time points (i.e. Week 1 till 12) of the within-subjects factor. These have been given the labels "Set 1", "Set 2" and "Set 3", respectively. A repeated measure analysis was conducted to examine changes in vocabulary performance across 12 weekly sets in a group of low-proficiency ESL students (N = 41).

Before conducting the main repeated measures ANOVA, a series of preliminary assumption tests were performed to ensure the reliability of the data and the appropriateness of the chosen analysis. These included checks for outliers, normality of distribution, and sphericity. By first establishing that the data met these assumptions, the subsequent repeated measure analysis could accurately reflect whether the learners' vocabulary performance changed significantly over time following the introduction of MAVR activities.

Assumption Test

Preliminary tests for normality, outliers, and sphericity were conducted prior to the main analysis, confirming suitability for parametric procedures. A one-way repeated measures ANOVA was then used to determine whether vocabulary scores significantly differed across the 12 sets. Where sphericity was violated, Greenhouse-Geisser corrections were applied. In addition to significance testing, effect sizes (partial eta squared) were calculated to assess the practical significance of the intervention over time. Pairwise comparisons with Bonferroni adjustments were conducted to identify specific time points with significant gains.

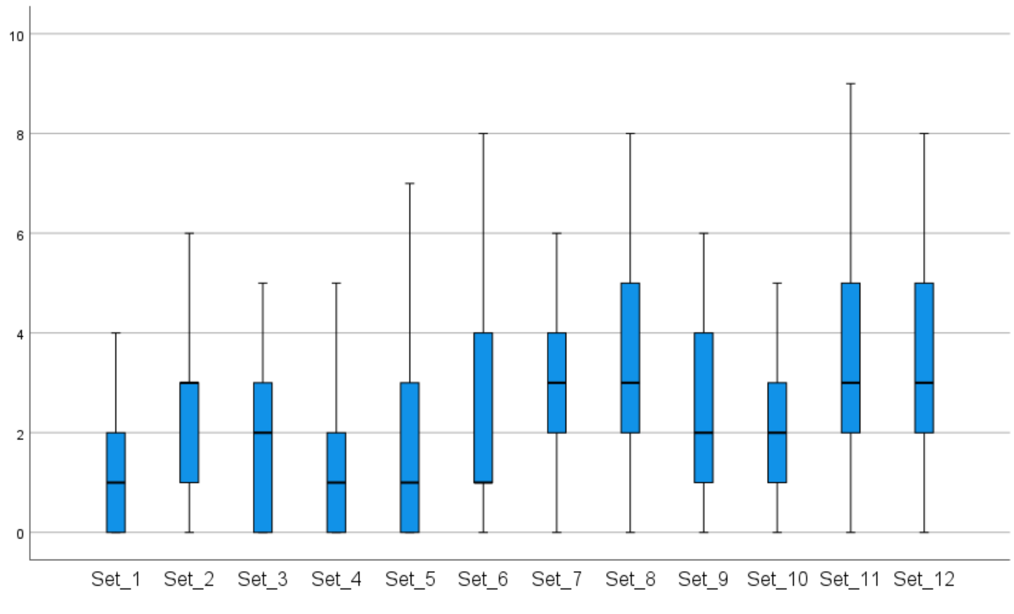


Figure 4 Boxplot of vocabulary scores showing the absence of outliers

It can be seen that there is no outliers in the data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. In order to understand whether the scores in each set of the within-subjects factor are normally distributed, Shapiro-Wilk is referred as below;

Table 1 Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Set_1	.060	41	.000	.813	41	.060
Set_2	.074	41	.010	.913	41	.074
Set_3	.051	41	.004	.893	41	.051
Set_4	.070	41	.000	.807	41	.070
Set_5	.050	41	.001	.847	41	.050
Set_6	.064	41	.000	.854	41	.064
Set_7	.054	41	.031	.943	41	.054
Set_8	.052	41	.052	.940	41	.052
Set_9	.061	41	.000	.897	41	.061
Set_10	.056	41	.000	.904	41	.056
Set_11	.075	41	.004	.951	41	.075
Set_12	.098	41	.056	.954	41	.098
a. Lilliefors Significance Correction						

In the table above, it can see that all of the significant values are greater than .05. Therefore, the dependent variable, Vocabulary scores, is normally distributed for each level of the within-subjects factor, time (Week 1 – Week 12). This is equivalent to stating that scores from Week 1 (Set 1) until Week 12 (Set 12) are all normally distributed as assessed by Shapiro-Wilk's test ($p > .05$).

Descriptive statistics

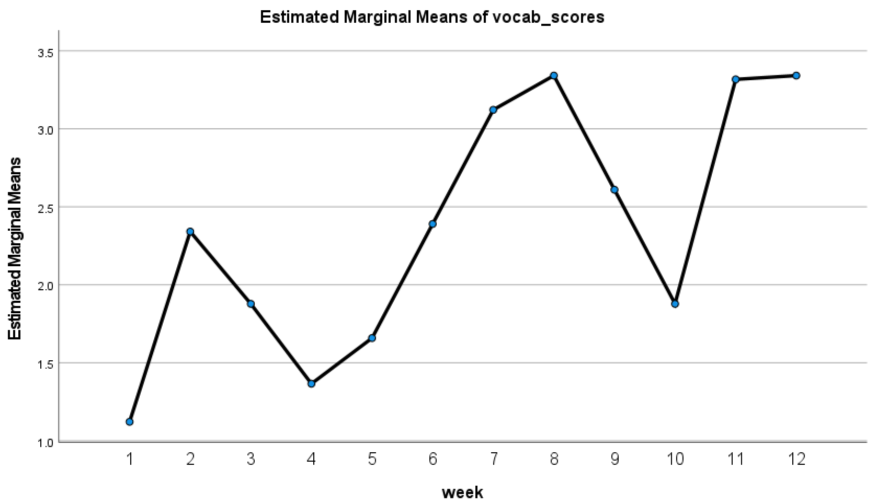
Profile Plot and Mean Trends

Descriptive results showed slight variations in scores, with means ranging from 1.12 to 3.34. The linear trend analysis revealed of increasing at each successive time point (i.e. Week 1 till Week 8) and decreasing in the subsequent week (Week 9 to 10) before picking up back to 2.0 (Week 11 to 12). This indicates fluctuations in vocabulary performance across the twelve measurement points. Despite these fluctuations, the overall pattern suggested higher vocabulary scores during the later measurements points than during the initial measurement points. This can be seen in the profile plot as shown below in which the profile plot clearly shows that vocabulary scores increased at each successive time point initially, but decrease sharply from time point 9 to 10 which seemingly greater than that from time point 2 to 4:

Table 2 Descriptive Statistics

	Mean	Std. Deviation	N
Set_1	1.12	1.208	41

Set_2	2.34	1.769	41
Set_3	1.88	1.600	41
Set_4	1.37	1.513	41
Set_5	1.66	1.797	41
Set_6	2.39	2.120	41
Set_7	3.12	1.631	41
Set_8	3.34	2.276	41
Set_9	2.61	1.829	41
Set_10	1.88	1.503	41
Set_11	3.32	2.091	41
Set_12	3.34	2.032	41



This descriptive statistic shows the overall impression of the data, but to know whether the means between the levels of the within-subjects factor are statistically significantly different, a one-way repeated measures ANOVA is conducted.

Test of Sphericity

Table 3 Mauchly's Test of Sphericity[a]

Measure: vocab_scores							
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
week	.089	87.379	65	.036	.719	.914	.091

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.
a. Design: Intercept Within Subjects Design: week
b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Mauchly's Test of Sphericity indicated that the assumption of sphericity was violated, $\chi^2(65) = 87.379$, $p < .05$. Therefore, degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ($\varepsilon = .719$).

Repeated Measures ANOVA

Table 4 Tests of Within-Subjects Effects

Measure: vocab_scores							
Source		**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
week	**Sphericity Assumed**	285.535	11	25.958	18.435	.000	.315
	Greenhouse-Geisser	285.535	7.913	36.084	18.435	.000	.315
	Huynh-Feldt	285.535	10.049	28.414	18.435	.000	.315
	Lower-bound	285.535	1.000	285.535	18.435	.000	.315
Error(week)	**Sphericity Assumed**	619.549	440	1.408			
	Greenhouse-Geisser	619.549	316.525	1.957			
	Huynh-Feldt	619.549	401.957	1.541			
	Lower-bound	619.549	40.000	15.489			

Epsilon (ε) was 0.719, as calculated according to Greenhouse and Geisser (1959), and was used to correct the one-way repeated measures ANOVA. It was found that Vocabulary scores differed significantly across the 12 measurement occasions, $F(7.913, 316.525) = 18.435$, $p < .0005$. In other words, the mean of at least one level of the within-subjects factor is different from the mean of at least one other level. The effect size was large, $F(7.913, 316.525) = 18.435$, partial $\eta 2 = .315$, indicating that the MAVR intervention produced substantial improvements in vocabulary scores over time, according to Cohen (1988) effect size benchmark. This indicates substantial differences in vocabulary performance across the 12 measurement points.

In order to determine where the mean differences between the levels of the within-subjects factor lie, a post hoc test (Appendix A – Table Pairwise Comparison) was used. Bonferroni-adjusted pairwise comparisons showed that vocabulary scores at Week 12 were significantly higher than those at Weeks 1, 2, 3, 4, 5, 6, and 10 (all $p < .05$). Specifically, comparisons with Week 1 (mean difference = 2.22, 95% CI [1.03, 3.41], $p < .001$), Week 2 (mean difference = 1.00, 95% CI [0.09, 1.91], $p = .017$), and Week 10 (mean difference = 1.46, 95% CI [0.63, 2.30], $p < .001$) are presented as representative examples. However, no significant differences were observed between Week 12 and Weeks 7, 8, 9, or 11 (all $p > .05$). Overall, there was a statistically significant difference between means at the different time points. Therefore, the null hypothesis can be rejected and indicated statistically significant differences across the measurement points. It can be concluded that the analysis indicates that learners demonstrated measurable vocabulary growth over the twelve-week intervention. These findings indicate meaningful change in vocabulary performance over time, although the fluctuating trajectory suggests that improvement was not uniformly progressive across all measurement occasions.

DISCUSSION

The results of this study indicate that the incorporation of Mobile Augmented and Virtual Reality (MAVR) into English language instruction was associated with meaningful improvements in vocabulary acquisition for low-proficiency learners in rural contexts. These gains were particularly notable in the latter stages of the intervention, reflecting increased familiarity with the MAVR tools and greater engagement over time. The large effect size observed (partial $\eta^2 = .315$) underscores the practical significance of the findings and highlights the potential of AR and VR in educational interventions targeting underserved populations. This pattern suggests that the level of material difficulty and the design of instructional content play crucial roles in influencing learners' performance and motivation. When the materials were appropriately scaffolded and contextualised, learners demonstrated renewed engagement and improved retention, leading to steady gains in vocabulary mastery over time.

In this study, MAVR-based learning materials were specifically developed to bridge the gap between abstract language concepts and real-world understanding. By enabling learners to interact with digital objects and immersive scenes that represent vocabulary items, MAVR transformed abstract words into tangible, visual, and experiential elements. This helped low-proficiency learners, particularly those from rural schools, to relate new vocabulary to familiar real-world contexts, thereby enhancing comprehension and long-term retention. These results affirm Mayer's (2005) Cognitive Theory of Multimedia Learning, showing that the combination of visual, spatial, and verbal inputs enhances cognitive processing for abstract vocabulary concepts. Additionally, the immersive nature of MAVR aligns with principles of experiential learning (Knutson, 2003), enabling learners to build direct associations between words and contextualized actions or objects, which is particularly beneficial for students with limited language exposure beyond the classroom.

Furthermore, the study demonstrates that simulation-based learning using MAVR can promote learner autonomy and engagement through exploration and interaction, aligning with the principles of experiential learning theory (Knutson, 2003; Žukauskaitė, 2021). For low-proficiency learners who often struggle with traditional text-based materials, MAVR offers an alternative pathway to learning that is both engaging and accessible. The immersive experience not only aids in comprehension but also encourages curiosity, motivation, and enjoyment; factors that are often lacking in conventional ESL classrooms.

From a pedagogical standpoint, the results support the inclusion of MAVR as an innovative extension to the ADDIE Instructional Design Model, particularly in the design and development phases where digital interactivity can be embedded to enhance learning outcomes. The study thus contributes to both educational technology and language pedagogy by demonstrating that the thoughtful integration of MAVR can lead to measurable improvements in vocabulary acquisition among low-proficiency learners in rural settings.

Despite the promising outcomes, this study has key limitations. Without a control group, the internal validity is reduced, and improvements cannot be definitively attributed to MAVR alone. In addition, the short-term nature of the study limits claims about long-term retention. Future research should include comparative designs such as randomized control trials or between-group analyses and should extend the focus to other language skills or demographic groups to determine generalizability.

Nonetheless, the use of MAVR in language education holds significant potential for making English learning more meaningful, contextual, and equitable. By visualizing and interacting with vocabulary in a simulated environment, learners can better internalize language concepts that were once abstract or difficult to grasp. Future research could extend this study by applying MAVR across other language skills such as reading comprehension or sentence construction, or by comparing its impact with other technology-enhanced learning approaches to further validate its effectiveness.

CONCLUSION

This study demonstrates that Mobile Augmented and Virtual Reality (MAVR) may enhance vocabulary learning among low-proficiency ESL learners in rural primary schools. By integrating realistic visual content and immersive interaction, the MAVR intervention supported learners in making concrete connections between abstract vocabulary and meaningful contexts, leading to significant and sustained improvements across 12 time points. These findings not only validate the pedagogical value of AR and VR within the Cognitive Theory of Multimedia Learning but also highlight the potential of technology to reduce educational disparities in under-resourced settings. Future work may extend this approach to other language skills or compare MAVR with traditional instructional methods to further strengthen the evidence base for immersive technologies in language education.

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APPENDICES

Appendix A

Pairwise Comparisons

Measure: vocab_scores

(I) week	(J) week	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-1.220*	.246	.001	-2.116	-.323
	3	-.756	.239	.195	-1.627	.115
	4	-.244	.246	1.000	-1.142	.655
	5	-.537	.240	1.000	-1.411	.337
	6	-1.268*	.306	.012	-2.386	-.151
	7	-2.000*	.279	.000	-3.019	-.981
	8	-2.220*	.338	.000	-3.451	-.988
	9	-1.488*	.250	.000	-2.398	-.577
	10	-.756	.249	.276	-1.664	.151
	11	-2.195*	.348	.000	-3.464	-.927
	12	-2.220*	.327	.000	-3.411	-1.028
2	1	1.220*	.246	.001	.323	2.116
	3	.463	.198	1.000	-.258	1.185
	4	.976*	.248	.022	.071	1.881
	5	.683	.253	.667	-.239	1.605
	6	-.049	.281	1.000	-1.075	.978
	7	-.780	.241	.158	-1.658	.097
	8	-1.000	.300	.124	-2.096	.096
	9	-.268	.226	1.000	-1.094	.557
	10	.463	.224	1.000	-.353	1.280
	11	-.976	.313	.225	-2.118	.167

	12	-1.000*	.249	.017	-1.909	-.091
3	1	.756	.239	.195	-.115	1.627
	2	-.463	.198	1.000	-1.185	.258
	4	.512	.213	1.000	-.264	1.288
	5	.220	.205	1.000	-.529	.968
	6	-.512	.245	1.000	-1.405	.380
	7	-1.244*	.251	.001	-2.160	-.327
	8	-1.463*	.344	.008	-2.718	-.209
	9	-.732	.232	.199	-1.577	.113
	10	.000	.221	1.000	-.805	.805
	11	-1.439*	.288	.001	-2.490	-.388
	12	-1.463*	.240	.000	-2.337	-.589
4	1	.244	.246	1.000	-.655	1.142
	2	-.976*	.248	.022	-1.881	-.071
	3	-.512	.213	1.000	-1.288	.264
	5	-.293	.168	1.000	-.907	.321
	6	-1.024*	.246	.010	-1.920	-.129
	7	-1.756*	.241	.000	-2.636	-.876
	8	-1.976*	.274	.000	-2.974	-.977
	9	-1.244*	.234	.000	-2.096	-.392
	10	-.512	.216	1.000	-1.299	.274
	11	-1.951*	.270	.000	-2.937	-.965
	12	-1.976*	.262	.000	-2.933	-1.018
5	1	.537	.240	1.000	-.337	1.411
	2	-.683	.253	.667	-1.605	.239
	3	-.220	.205	1.000	-.968	.529
	4	.293	.168	1.000	-.321	.907
	6	-.732	.224	.146	-1.547	.084

	7	-1.463*	.277	.000	-2.475	-.452
	8	-1.683*	.297	.000	-2.767	-.599
	9	-.951*	.206	.003	-1.704	-.198
	10	-.220	.199	1.000	-.946	.507
	11	-1.659*	.260	.000	-2.608	-.709
	12	-1.683*	.217	.000	-2.472	-.893
6	1	1.268*	.306	.012	.151	2.386
	2	.049	.281	1.000	-.978	1.075
	3	.512	.245	1.000	-.380	1.405
	4	1.024*	.246	.010	.129	1.920
	5	.732	.224	.146	-.084	1.547
	7	-.732	.284	.904	-1.767	.303
	8	-.951	.318	.313	-2.111	.209
	9	-.220	.263	1.000	-1.177	.738
	10	.512	.257	1.000	-.425	1.449
	11	-.927	.307	.292	-2.047	.194
	12	-.951*	.254	.038	-1.878	-.025
7	1	2.000*	.279	.000	.981	3.019
	2	.780	.241	.158	-.097	1.658
	3	1.244*	.251	.001	.327	2.160
	4	1.756*	.241	.000	.876	2.636
	5	1.463*	.277	.000	.452	2.475
	6	.732	.284	.904	-.303	1.767
	8	-.220	.299	1.000	-1.311	.872
	9	.512	.245	1.000	-.380	1.405
	10	1.244*	.246	.001	.345	2.142
	11	-.195	.291	1.000	-1.255	.864
	12	-.220	.255	1.000	-1.151	.712

8	1	2.220*	.338	.000	.988	3.451
	2	1.000	.300	.124	-.096	2.096
	3	1.463*	.344	.008	.209	2.718
	4	1.976*	.274	.000	.977	2.974
	5	1.683*	.297	.000	.599	2.767
	6	.951	.318	.313	-.209	2.111
	7	.220	.299	1.000	-.872	1.311
	9	.732	.282	.861	-.295	1.759
	10	1.463*	.284	.000	.428	2.499
	11	.024	.332	1.000	-1.187	1.236
	12	.000	.318	1.000	-1.160	1.160
9	1	1.488*	.250	.000	.577	2.398
	2	.268	.226	1.000	-.557	1.094
	3	.732	.232	.199	-.113	1.577
	4	1.244*	.234	.000	.392	2.096
	5	.951*	.206	.003	.198	1.704
	6	.220	.263	1.000	-.738	1.177
	7	-.512	.245	1.000	-1.405	.380
	8	-.732	.282	.861	-1.759	.295
	10	.732	.234	.220	-.123	1.586
	11	-.707	.276	.930	-1.712	.297
	12	-.732	.212	.090	-1.507	.043
10	1	.756	.249	.276	-.151	1.664
	2	-.463	.224	1.000	-1.280	.353
	3	.000	.221	1.000	-.805	.805
	4	.512	.216	1.000	-.274	1.299
	5	.220	.199	1.000	-.507	.946
	6	-.512	.257	1.000	-1.449	.425

	7	-1.244*	.246	.001	-2.142	-.345
	8	-1.463*	.284	.000	-2.499	-.428
	9	-.732	.234	.220	-1.586	.123
	11	-1.439*	.247	.000	-2.340	-.538
	12	-1.463*	.229	.000	-2.299	-.627
11	1	2.195*	.348	.000	.927	3.464
	2	.976	.313	.225	-.167	2.118
	3	1.439*	.288	.001	.388	2.490
	4	1.951*	.270	.000	.965	2.937
	5	1.659*	.260	.000	.709	2.608
	6	.927	.307	.292	-.194	2.047
	7	.195	.291	1.000	-.864	1.255
	8	-.024	.332	1.000	-1.236	1.187
	9	.707	.276	.930	-.297	1.712
	10	1.439*	.247	.000	.538	2.340
	12	-.024	.246	1.000	-.920	.871
12	1	2.220*	.327	.000	1.028	3.411
	2	1.000*	.249	.017	.091	1.909
	3	1.463*	.240	.000	.589	2.337
	4	1.976*	.262	.000	1.018	2.933
	5	1.683*	.217	.000	.893	2.472
	6	.951*	.254	.038	.025	1.878
	7	.220	.255	1.000	-.712	1.151
	8	.000	.318	1.000	-1.160	1.160
	9	.732	.212	.090	-.043	1.507
	10	1.463*	.229	.000	.627	2.299
	11	.024	.246	1.000	-.871	.920
Based on estimated marginal means						

*. The mean difference is significant at the .05 level.
b. Adjustment for multiple comparisons: Bonferroni.