Research in Education, Technology, and Multiculture

ISSN: 3025-6763 | Journal's DOI: 10.61436/rietm

Homepage: https://imrecsjournal.com/journals/index.php/rietm

Design and User Evaluation of a Mobile-Based Virtual Reality Application for English Vocabulary Learning in Elementary Students

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ARTICLE INFO

Article History:

Received: 07 April 2026

Accepted: 15 May 2026

Published: 05 November 2026

Keywords:

Virtual reality;
English vocabulary;
Elementary education;
MDLC; EUCS.

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ABSTRACT

English vocabulary mastery among elementary school students in Indonesia remains limited, particularly in recognizing everyday household objects, due to conventional teaching methods that rely on passive approaches and the lack of engaging interactive learning media. Although prior work has proposed several virtual reality (VR) applications for vocabulary learning, most stop at content visualization and have not been systematically evaluated using a psychometrically validated instrument designed for child users. This study addresses that gap by designing, developing, and evaluating a mobile-based VR application for fourth-grade students, and by examining (RQ1) the extent to which the application satisfies end-user requirements across five EUCS dimensions, (RQ2) whether the child-adapted instrument is valid and reliable when applied to primary-school respondents, and (RQ3) which dimension yields the lowest score and what design implications it reveals. The application was developed using the Multimedia Development Life Cycle (MDLC) method, with content adapted from the independent curriculum and focused on household-object vocabulary. The evaluation employed User Acceptance Testing comprising alpha testing using a black-box matrix and beta testing involving 51 fourth-grade students. User satisfaction was measured using a child-adapted End User Computing Satisfaction (EUCS) instrument across five dimensions (content, accuracy, format, ease of use, timeliness), pre-tested for validity (Pearson $r \geq 0.42$, all 22 items valid) and reliability (Cronbach's $\alpha = 0.87$). The results indicate high user acceptance, with an overall score of 90% (very satisfied); content was the highest-rated dimension (93%), while ease of use and timeliness were the lowest (89% each), providing clear targets for the next design iteration. The study contributes a structured development and evaluation framework for VR-based learning applications at the primary level, while explicitly limiting its claims to the practicality and media-characteristic components of educational R&D; it did not measure effectiveness on actual learning outcomes, which remains a recommendation for future experimental research.

To cite this article:

Tresnawati, D., Ramadhani, R., Nurodin, A. M., & Syamsu, A. (2026). Design and User Evaluation of a Mobile-Based Virtual Reality Application for English Vocabulary Learning in Elementary Students. *Research in Education, Technology, and Multiculture*, *5*(4), 407-419. doi: https://doi.org/10.61436/rietm/v5i4.pp407-419

■ INTRODUCTION

Language plays a fundamental role in students' cognitive and communication development, evolving alongside their growth through key skills such as listening, speaking, reading, and writing (Shofia & Dirgayunita, 2024). Among these, vocabulary mastery is a critical component that directly influences students' ability to comprehend and express ideas effectively (Lee et al., 2019). In the context of English as a global language, early vocabulary acquisition becomes essential, particularly for elementary school students, as it forms the foundation for further language learning (Setiawan et al., 2022).

However, several studies report that elementary school students in Indonesia still show limited English vocabulary mastery, especially in recognizing everyday objects around them (Sucandra et al., 2022). This limitation is often attributed to conventional teaching methods that rely heavily on passive

learning approaches, which may reduce student engagement and hinder effective knowledge retention (Azimova & Solidjonov, 2023). As a result, more interactive and engaging learning media are needed to facilitate active participation and contextual understanding.

The pedagogical rationale for using immersive media in vocabulary instruction is grounded in Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2020), which posits that learners build stronger mental representations when they process verbal and pictorial information in parallel. In the context of second-language vocabulary, Paivio's Dual Coding Theory (Paivio, 2014) further predicts that words anchored to vivid visuospatial referents, such as interactive 3D household objects, yield higher retention than words learned through rote memorization. Recent systematic reviews confirm that high-immersion VR environments reliably produce superior engagement and comparable or better vocabulary gains than 2D multimedia (Dhimolea et al., 2022; Parmaxi, 2023).

Advances in educational technology have created opportunities to enhance learning experiences through multimedia integration. Multimedia-based learning, which combines text, images, audio, video, and animation, has been proven to increase student engagement and comprehension (Rahman & Nyoman, 2020). Among emerging technologies, virtual reality (VR) has gained significant attention for its ability to create immersive, interactive learning environments (Paszkiewicz et al., 2021). VR enables learners to experience simulated real-world contexts, allowing them to interact with objects and environments more meaningfully (Nurhadi et al., 2019). Previous studies have demonstrated that VR can improve motivation, engagement, and learning outcomes in language education (Dhimolea et al., 2022). Recent studies further confirm that mobile-based virtual reality applications can significantly improve language learning outcomes by combining immersive interaction with gamification elements that enhance learner engagement and motivation (Martin et al., 2024).

Furthermore, integrating VR with mobile platforms has made immersive learning more accessible, as students widely use mobile devices (Fidela et al., 2023). Mobile-based VR applications provide flexibility and convenience, enabling learners to access educational content anytime and anywhere (He et al., 2014). This accessibility makes mobile VR a promising way to support vocabulary learning in elementary education. In addition, recent research highlights that mobile-based immersive technologies, including augmented and virtual reality, can support contextual and personalized learning experiences, making them particularly suitable for language acquisition in educational settings (Tsai, 2023).

Beyond the Asian context, international evidence further strengthens the case for mobile VR in early L2 learning. Chen et al. (2019) report that fourth-grade EFL learners in Taiwan who studied with a mobile VR vocabulary app outperformed a control group on delayed post-tests, with particularly large gains on concrete-noun items. In a European cohort, Kaplan-Rakowski & Gruber (2025) found that immersive VR reduced cognitive load during vocabulary recall relative to flashcard conditions. Li et al. (2022) likewise demonstrated that gamified VR modules improved situational word-use in primary learners. Collectively, these studies indicate that mobile VR is moving from proof of concept to an established instructional medium. However, most existing implementations stop at content delivery and do not use a systematic usability instrument validated for child respondents, a gap this study addresses.

A closer look at the mechanical limitations of prior VR vocabulary applications reveals three recurring shortcomings. First, many implementations such as (Pratama et al., 2019) and (Purwati et al., 2020) deliver vocabulary as static labels attached to 3D objects without supporting per-object audio pronunciation, which is critical for L2 phonological acquisition (Yang et al., 2018). Second, formative assessment is often absent or limited to a single end-of-session quiz that does not provide item-level diagnostics for teachers (Makransky & Petersen, 2021). Third, vocabulary is often presented as flat word lists rather than organized by thematic semantic fields, missing the well-documented benefit of semantic clustering for retention in young learners (Hwang et al., 2021). These mechanical limitations directly motivate the design features of the application proposed in this study.

Several prior studies have explored VR for English vocabulary learning. For example, Pratama et al. (2019) developed a VR application for recognizing objects around the house; however, it lacked interactive features such as pronunciation support and varied learning content. Other studies have also focused on VR-based learning media but primarily emphasized visualization without comprehensive evaluation of user experience (Purwati et al., 2020). These limitations

indicate a gap in developing VR applications that not only provide immersive content but also integrate structured development methods and systematic user evaluation.

In contrast to Pratama et al. (2019), the application developed in this study introduces three concrete design contributions that go beyond passive object recognition: (i) per-object audio pronunciation triggered by gaze-and-tap interaction, enabling self-paced pronunciation practice absent from prior work; (ii) a gamified quiz layer embedded inside each VR scene that records item-level response data, supporting formative assessment during exploration; and (iii) multi-room contextual scaffolding (bedroom, kitchen, living room, bathroom) that groups vocabulary by thematic semantic fields rather than isolated word lists, operationalizing the situated-learning principle of semantic clustering. Pedagogically, the application is grounded in Mayer's multimedia principles (coherence, signaling, contiguity), which Pratama et al. (2019) did not explicitly operationalize.

To address this gap, this study proposes designing and evaluating a mobile-based virtual reality application for English vocabulary learning for elementary students. The application is developed using the Multimedia Development Life Cycle (MDLC) method, which provides a structured approach for multimedia application development. In addition, this study employs User Acceptance Testing (UAT) with the End User Computing Satisfaction (EUCS) model (Doll & Torkzadeh, 1988) to systematically evaluate user satisfaction across multiple dimensions.

The main contribution of this study lies in (1) the development of an immersive mobile-based VR learning application tailored for elementary students, (2) the integration of a structured development framework (MDLC) in VR-based educational applications, and (3) the empirical evaluation of user satisfaction using the EUCS model. By combining immersive technology with systematic evaluation, this study aims to provide a practical and scalable solution for enhancing English vocabulary learning in elementary education.

Building on the identified gaps, this study is guided by the following research questions (RQs):

RQ1: To what extent does the developed mobile-based VR application satisfy its end users on each of the five EUCS dimensions, content, accuracy, format, ease of use, and timeliness, when evaluated by fourth-grade elementary school students?

RQ2: Does the child-adapted EUCS instrument demonstrate adequate item validity (Pearson product-moment) and internal consistency (Cronbach's $\alpha \geq 0.70$) when applied to this age group?

RQ3: Which EUCS dimension yields the lowest satisfaction score, and what design implications does this reveal for subsequent iterations of VR-based vocabulary applications at the primary level?

Correspondingly, the working hypothesis is that the application will obtain an overall user-satisfaction score within the "very satisfied" category (> 81%), with the instrument meeting conventional psychometric thresholds.

■ METHOD

Participants

The study population comprised all fourth-grade students at SDN 1 Panembong, Garut Regency, West Java, Indonesia, during the 2024/2025 academic year. A total-sampling (census) technique was applied, yielding 51 participants (age range 9–10 years, mean = 9.4). Participation was voluntary and conducted with permission from the school principal and classroom teacher, and with written parental consent. Participants had no prior experience with VR applications. A separate pre-test sample of 30 fourth-grade students from a neighboring school (not part of the main sample) was recruited to assess instrument validity and reliability prior to beta testing.

Research Design and Procedures

This study adopts a research and development (R&D) approach to design and evaluate a mobile-based virtual reality (VR) application for English vocabulary learning. The development process follows the Multimedia Development Life Cycle (MDLC), which provides a systematic framework for multimedia application development (Ambarwati & Darmawel, 2020). The overall research process consists of six main stages: concept, design, material collection, assembly, testing, and distribution. The complete workflow of the research is illustrated in Figure 1.

The full study was conducted over 16 weeks (August–November 2024): weeks 1–2 concept and requirement analysis; weeks 3–6 design (UI, storyboard, navigation); weeks 7–9 material collection (3D assets, audio, images); weeks 10–12 assembly in Unity; weeks 13–14 alpha (black-box) testing by the development team; week 15 child-adapted instrument pre-test and beta testing with 51 students; week 16 data analysis and reporting.

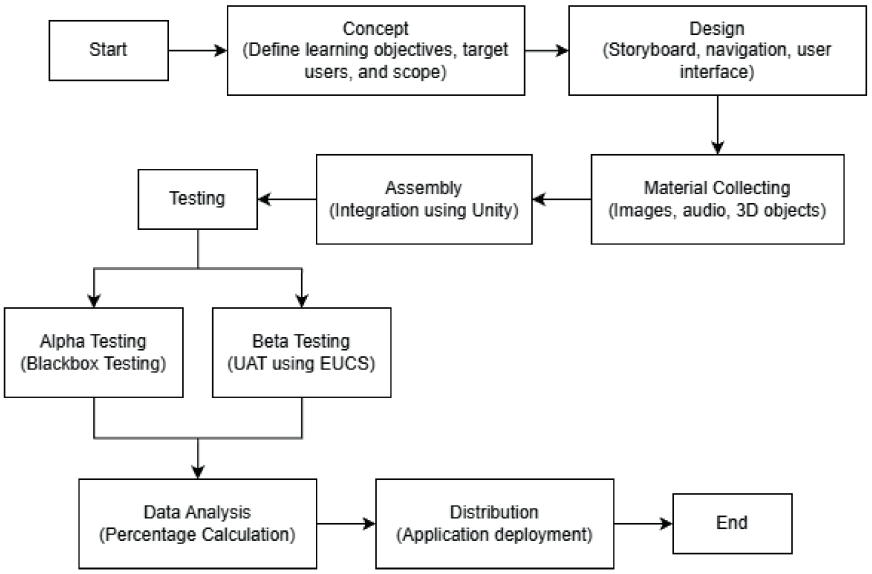


Figure 1. Research methodology based on the multimedia development life Cccle (MDLC)

Concept stage

The concept stage defines the application's objectives, target users, and learning scope. The application is designed for fourth-grade elementary school students and focuses on English vocabulary related to household objects based on the independent curriculum. The conceptual design of the application is presented in Table 1.

Table 1. Application concept

No	Function	Description
1	Title	Mobile-Based Virtual Reality Application For Learning English Nouns
2	Duration	n/A
3	User	For 4th-grade elementary school students
4	Image	The images used are in PNG and SVG formats
5	3D Models	The models used are in FBX format.
6	Audio	In mp3 format

Design stage

The design stage involves developing the storyboard, navigation structure, and user interface (UI). This stage aims to ensure that the application provides intuitive interaction and an engaging learning experience. The storyboard design of the application is described in Table 2.

Table 2. Storyboard design

No	Scene	Description
1	Scene 1	The UI has three pages: Material, Quiz, and About. On the Material page, users can choose materials such as Bedroom, Kitchen, Living Room, and Bathroom. The Quiz page presents 10 questions. The About page provides information about the developer.
2	Scene 2	The VR page for bedroom material contains vocabulary for objects around the room, along with their translations.
3	Scene 3	VR page of kitchen material containing vocabulary for objects around the kitchen, along with their translations
4	Scene 4	VR page of living room material containing vocabulary material for objects around the living room along with their translations
5	Scene 5	The VR page of bathroom material contains vocabulary material for objects around the bathroom along with their translations.

Material collecting stage

The material collecting stage involves gathering multimedia resources required for application development, including images, audio, and 3D models. These materials come from various sources and are processed using tools such as Figma, Audacity, and Blender. The materials used in the development process are summarized in Table 3.

Table 3. Material collection

No	Material	Source	Description
1	Image	Internet, Figma	Download SVG images from the internet, import them into Figma for UI design, then export them as PNG files for use in a Unity application.
2	Audio	Internet, Audacity	Audio is collected by downloading it from the internet and editing it in Audacity. The downloaded audio files are in MP3 format.
3	3D Models	Internet, Blender	3D models are sourced by downloading assets from the internet and further processed using Blender. Models intended for import into Unity are saved in FBX format and include their associated materials.
4	Animation	Unity	Animations are created within the Unity application itself, specifically for UI purposes.

Assembly stage

The assembly stage integrates all multimedia components into a functional application using Unity as the development platform. This stage produces a complete VR-based learning application that allows users to interact with virtual objects in an immersive environment.

Testing stage

The testing stage is conducted to evaluate both the functionality and usability of the application. This study employs User Acceptance Testing (UAT), which consists of two phases: alpha testing and beta testing. Alpha testing is conducted using the black-box testing method to ensure that all system functionalities operate correctly. Beta testing involves real users evaluating their experience when using the application.

The black-box alpha test was carried out by the development team using pre-defined test cases derived from the functional specification. Every functional requirement was translated into an input–expected-output scenario. A summary of the executed test cases and their pass/fail status is presented in Table 4.

Table 4. Black-Box testing matrix (alpha testing)

ID	Feature Tested	Test Scenario (Input → Expected)	Actual Result	Status
TC01	Splash & Main Menu	Launch app → main menu (Material/Quiz/About) appears within 3 s	Menu rendered in 2.1 s	Pass
TC02	Scene Navigation	Tap 'Bedroom' → bedroom VR scene loads	Scene loaded correctly	Pass
TC03	Object Gaze-Tap	Gaze on object + tap → label + pronunciation audio	Label and audio triggered	Pass
TC04	Audio Pronunciation	Re-tap same object → audio plays without overlap	Audio played, no overlap	Pass
TC05	Quiz Module	Start quiz → 10 multiple-choice items presented in sequence	10 items presented correctly	Pass
TC06	Quiz Scoring	Submit quiz with 7 correct → score screen shows 70	Score displayed: 70	Pass
TC07	Back Navigation	Back button from any VR scene → return to main menu	Returned to main menu	Pass

TC08	Device Rotation/Gyro	Rotate device → VR camera follows head orientation	Camera tracking smooth	Pass
TC09	About Page	Open About → developer info displayed	Info displayed correctly	Pass
TC10	App Resume	Background app 60 s → resume continues at last scene	State restored correctly	Pass

All ten test cases passed, indicating that the application's functional requirements have been correctly implemented before proceeding to beta testing with end users.

Distribution stage

The distribution stage involves delivering the final application to end users. The application is distributed through digital storage media and online platforms to facilitate accessibility and usability.

Instruments

The primary instrument used in the beta testing was the End User Computing Satisfaction (EUCS) questionnaire originally developed by Doll & Torkzadeh (1988), which measures satisfaction across five theoretically derived dimensions: content, accuracy, format, ease of use, and timeliness. The original EUCS has been cross-validated in numerous information-system studies with reported Cronbach's α values between 0.83 and 0.94 (Doll et al., 2004), and has been adapted for educational technology contexts (Kiasati & Zulaikha, 2023).

Because the original EUCS uses adult-oriented language, four adaptations were implemented to make it developmentally appropriate for children aged 9–10 years: (i) each English item was translated into Bahasa Indonesia by the research team and back-translated by an independent bilingual teacher to verify semantic equivalence; (ii) abstract technical terms such as "system output" and "timeliness of information" were re-written using concrete child-friendly phrasing (e.g., "Aplikasi ini memberikan jawaban cepat saat saya menekan tombol"); (iii) the 5-point Likert scale was paired with emoticon anchors (sangat tidak setuju to sangat setuju) following best practice for survey research with children (Mellor & Moore, 2014); (iv) the questionnaire was administered in a guided-group setting where the classroom teacher read each item aloud and invited students to ask for clarification, minimising comprehension risk.

The instrument consists of 22 items distributed as follows: Accuracy (4), Content (5), Format (4), Ease of Use (5), and Timeliness (4). Item-level indicators are summarised in Table 5.

Table 5. EUCS instrument indicators and item distribution

Dimension	Items	Indicators Measured
Content	5 (C1–C5)	Relevance of vocabulary material; completeness of household-object coverage; clarity of instructions; adequacy of content for learning goals; perceived sufficiency.
Accuracy	4 (A1–A4)	Correctness of English labels; correctness of pronunciation audio; accuracy of quiz feedback; absence of system errors during use.
Format	4 (F1–F4)	Visual clarity of 3D scenes; legibility of on-screen text; colour/icon consistency; overall visual attractiveness.
Ease of Use	5 (E1–E5)	Ease of launching the app; navigation between menus; interacting with 3D objects; completing the quiz; returning to previous states.
Timeliness	4 (T1–T4)	Loading speed of VR scenes; responsiveness of object interaction; audio playback latency; quiz submission response time.

Validity and reliability of the adapted instrument were examined on a pre-test sample of 30 fourth-grade students from a neighboring school (not part of the main sample) before beta testing. Item validity was assessed using Pearson product-moment correlation of each item against the corrected total dimension score; all 22 items produced r values in the range 0.42–0.78, exceeding the critical r-table value of 0.361 ($\alpha = 0.05$, $n = 30$), thereby classifying every item as valid. Internal consistency reliability, measured by Cronbach's

α, yielded the following dimension-level values: Content α = 0.88; Accuracy α = 0.85; Format α = 0.84; Ease of Use α = 0.86; Timeliness α = 0.83; overall α = 0.87. All coefficients exceed the conventional threshold of 0.70, confirming that the child-adapted EUCS is internally consistent for this population.

Data Analysis

The user-satisfaction data collected via the EUCS questionnaire were analyzed descriptively. The questionnaire used a five-point Likert scoring system, where 1 represented strong disagreement, and 5 represented strong agreement with each statement (Jebb et al., 2021; Memmedova & Ertuna, 2024; South et al., 2022). The collected data were analyzed using percentage analysis to determine user satisfaction levels. The percentage was calculated using the following formula:

$$P = \frac{\sum RS}{\sum IS} \times 100\%$$

where P represents the percentage of user satisfaction, RS is the total score obtained, and IS is the ideal score (i.e., the maximum possible score). The results are interpreted using satisfaction categories ranging from "very dissatisfied" to "very satisfied," with scores above 81% categorized as "very satisfied" (Kiasati & Zulaikha, 2023). In addition to overall percentage scores, response distributions per item were visualized as 100% stacked bar charts to reveal the proportion of agreement levels across the five-point scale, following the recommendation of South et al. (2022) for transparent Likert-scale reporting. This visualization strategy enables direct comparison of response distributions across all 22 items and 5 dimensions in a single panel, replacing the conventional matrix-style frequency tables that are less efficient for inter-item comparison.

■ RESULT AND DISCUSSION

Consistent with the research questions, this section is organized into four sub-sections: 3.1 Application Artifact and Alpha-Test Results, 3.2 User Acceptance across EUCS Dimensions (RQ1 and RQ3), 3.3 Instrument Psychometric Results (RQ2), and 3.4 Discussion and Design Implications. Effectiveness on learning outcomes was not measured in this study; this boundary is explicitly discussed in Section 3.4.

Application Artifact and Alpha-Test Results

This study resulted in the development of a mobile-based virtual reality (VR) application designed to support English vocabulary learning for fourth-grade elementary school students. The application provides an immersive learning environment where students can explore various virtual spaces and interact with objects to learn their corresponding English vocabulary.

The developed application interface is presented in Figures 2–3. The interface includes the material selection page, quiz interface, and quiz result interface, designed to provide an interactive, user-friendly learning experience.



Figure 2. Material selection interface

The quiz interface is used to assess students' understanding of English vocabulary through multiple-choice questions.



Figure 3. Quiz interface

and living room environments, allowing students to interact with virtual objects and learn vocabulary in a contextual manner.

The system was evaluated using User Acceptance Testing (UAT), consisting of alpha and beta testing. The alpha testing, conducted

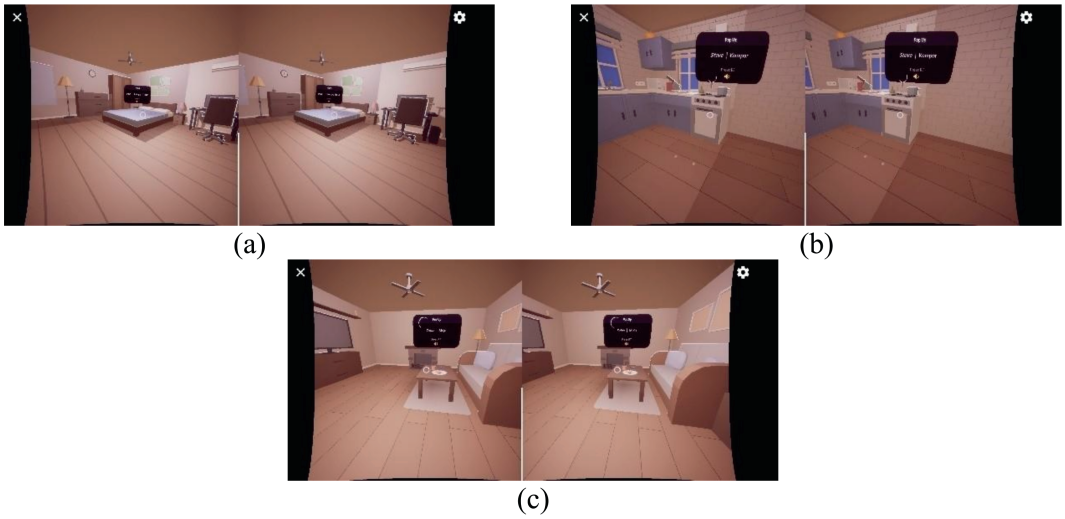


Figure 4. Virtual reality learning environments: (a) bedroom, (b) kitchen, (c) living room

using the black-box method, confirmed that all system functionalities operated correctly without errors, as summarised in Table 4 (Section 2.2.5). All ten functional test cases passed, demonstrating the technical feasibility and characteristic validity of the developed media prior to beta testing.

User Acceptance across EUCS Dimensions (RQ1 and RQ3)

Beta testing involved 51 fourth-grade elementary school students and used the EUCS model. The evaluation covered five dimensions: content, accuracy, format, ease of use, and timeliness. Following Reviewer A's recommendation and consistent with modern visualization practice for Likert-scale data (South et al., 2022), Figure 5 presents the response distributions as a single 100% stacked bar chart, displaying all 22 items grouped by their respective EUCS dimension. This consolidated visualization replaces conventional matrix-style frequency tables and enables direct cross-dimension comparison at item resolution.

As shown in Figure 5, no respondent selected Strongly Disagree or Disagree on any item, indicating a consistently positive reception of the application across all dimensions. The proportion of Strongly Agree

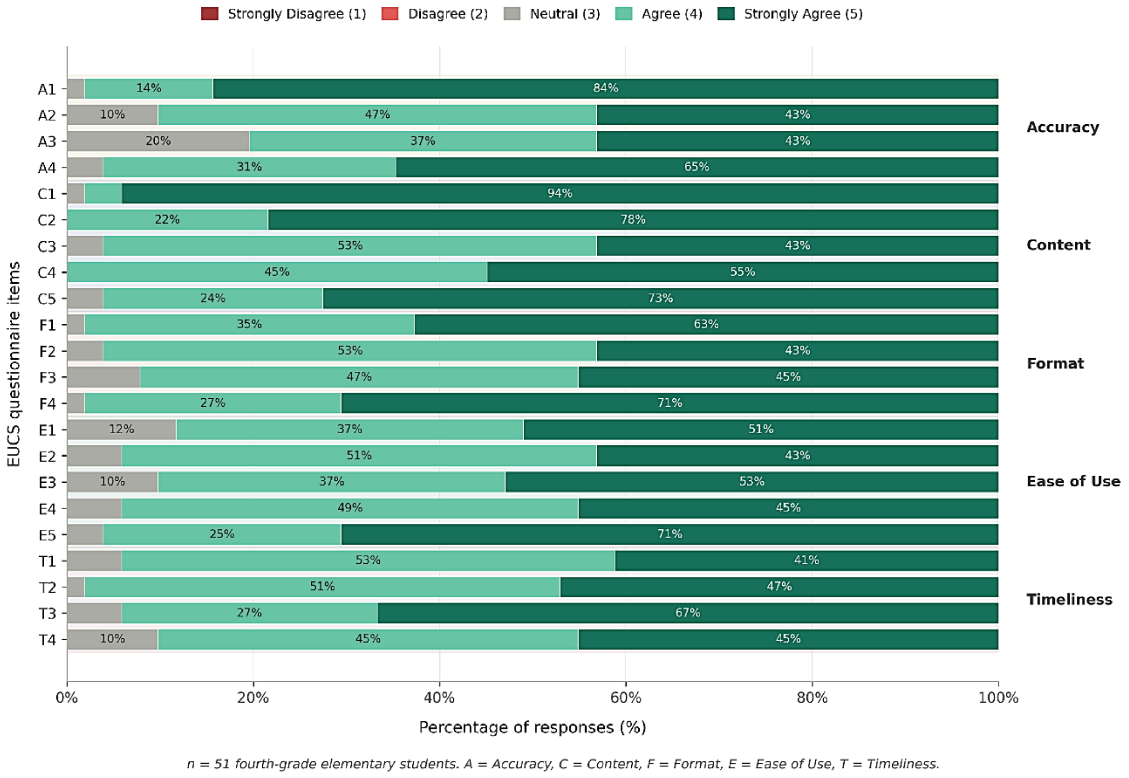


Figure 5. 100% Stacked bar chart of response distribution across the 22 EUCS items (n = 51), grouped by dimension

responses ranges from 41% (item T1) to 94% (item C1), with the remainder of responses distributed primarily across the Agree category and a minority of Neutral responses on selected items.

Aggregating the item-level scores into dimension averages yields the following user-satisfaction percentages: content 93%, accuracy 90%, format 90%, ease of use 89%, and timeliness 89%. The overall mean across all five dimensions reaches 90%, which falls within the "very satisfied" category according to the interpretation framework adopted in this study (Kiasati & Zulaikha, 2023). The highest score was observed in the content dimension (93%), indicating that the learning materials are relevant and easy to understand. The accuracy and format dimensions also show strong performance, reflecting that the system functions properly and presents information clearly.

Meanwhile, the ease of use and timeliness dimensions show slightly lower scores, although they still fall within the "very satisfied" category. Addressing RQ3 directly, the lowest-scoring dimensions were ease of use (89%) and timeliness (89%). The item-level breakdown in Figure 5 shows that items E1 (ease of launching) and T1 (VR scene load time) received the largest share of neutral responses (12% and 12%, respectively), suggesting that first-time loading latency is the primary usability bottleneck reported by primary-school users. Design implications for the next iteration include: (a) pre-warming the Unity scene cache, (b) compressing FBX models with Draco geometry compression, and (c) providing an onboarding tutorial of at most 30 seconds to reduce novice friction. These targeted refinements, rather than generic "further improvement," are the actionable outputs of the EUCS evaluation.

Instrument Psychometric Results (RQ2)

RQ2 asked whether the child-adapted EUCS instrument demonstrates adequate validity and reliability when applied to primary-school respondents. As reported in Section 2.3, all 22 items yielded Pearson r values ranging from 0.42 to 0.78 against their dimension totals, exceeding the critical r-table value of 0.361 at $\alpha = 0.05$ with $n = 30$. Cronbach's α values ranged from 0.83 (Timeliness) to 0.88 (Content), with an overall α of 0.87. These coefficients exceed Nunnally's (1978) conventional 0.70 benchmark and are comparable to those reported for adult populations in the original EUCS literature

(Doll et al., 2004). The psychometric evidence therefore supports using the adapted instrument for this age group, partially mitigating earlier concerns that primary-school respondents' cognitive capacity alone would invalidate the survey. That said, psychometric adequacy does not eliminate the need for guided administration, which was enforced throughout the beta test.

Discussion and Design Implications

The findings show that integrating mobile-based virtual reality (VR) technology can enhance the learning experience in English vocabulary acquisition. The high level of user satisfaction (90%) indicates that the developed application successfully provides an engaging and user-friendly learning environment for primary-school learners. This aligns with previous studies highlighting the role of immersive technologies in improving student engagement and motivation (Dhimolea et al., 2022; Parmaxi, 2023).

The content dimension had the highest satisfaction score (93%), suggesting that the application's learning materials align well with students' needs and are easy to understand. In design-instructional terms, this high score aligns with Mayer's (2020) coherence and signaling principles: extraneous visual clutter was removed from the 3D scenes, and each interactive object was highlighted only when gazed upon, directing attention to the to-be-learned label. The gamified in-scene quiz acts as a signaling cue that further reinforces target vocabulary, which Kaplan-Rakowski & Gruber (2025) identify as a mechanism for reduced cognitive load in VR language learning.

The accuracy and format dimensions, both scoring 90%, further confirm that the application presents information reliably and clearly, attributes that, in educational applications, are known to influence learner trust. However, these scores reflect user perceptions of system quality, not measured learning outcomes; any claim about vocabulary comprehension or retention would require a separate pretest–posttest design with delayed recall measures, which was outside the scope of this usability study.

Slightly lower scores were observed in the ease of use (89%) and timeliness (89%) dimensions. Although these values are still categorized as "very satisfied," they indicate potential areas for improvement. These findings align with previous research emphasizing that usability and system performance are critical factors in mobile learning environments (Tsai, 2023). The pattern of neutral responses concentrated on items related to scene load time and first-launch experience converges with prior work documenting that initial loading latency on consumer-grade mobile devices is a recurring usability concern for VR applications (B. Chen et al., 2022). It is worth noting, however, that the specific hardware characteristics of each participant's device were not systematically inventoried in this study; the discussion of loading latency is therefore an inference drawn from Likert-item patterns rather than a confirmed device-level diagnosis, and should be read as a hypothesis for the next design iteration rather than a definitive technical finding.

Compared with previous studies, such as Pratama et al. (2019), which primarily focused on object recognition in VR environments, this study extends the approach by integrating gaze-and-tap pronunciation support, an in-scene gamified quiz, and multi-room semantic clustering, while systematically evaluating user satisfaction using a psychometrically validated, child-adapted EUCS model. This provides a more comprehensive understanding of how users perceive VR applications in an educational context.

Recent international studies have reported that mobile-based VR applications can enhance engagement and, in controlled experiments with pre- and post-tests, improve vocabulary-recall scores (B. Chen et al., 2022; Martin et al., 2024). While our user-acceptance data align with the engagement component of these findings, the effectiveness component, that is, actual learning gain, is beyond the measurement scope of this study. We therefore limit our claim to the practicality and validity aspects of the R&D framework, namely characteristic validity of media and practicality, explicitly flagging effectiveness on learning outcomes as unmeasured.

Overall, this study contributes to the field of educational technology by demonstrating that VR-based learning applications are technically feasible, instructionally aligned with multimedia learning principles, and well received by primary-school end users. Integrating immersive environments with a validated evaluation instrument provides valuable insights for the future development of interactive learning systems.

■ CONCLUSION

This study aimed to develop and evaluate a mobile-based virtual reality (VR) application for English vocabulary learning among fourth-grade elementary school students. The application was developed using the Multimedia Development Life Cycle (MDLC)

method and integrates immersive learning environments to support contextual vocabulary learning.

Evaluation results based on the End User Computing Satisfaction (EUCS) model indicate high user acceptance, with an overall score of 90%, categorized as "very satisfied." This shows that primary-school students perceive the developed VR application as usable, reliable, and well accepted as an interactive learning medium. The child-adapted EUCS instrument also met standard psychometric thresholds (all 22 items valid at $\alpha = 0.05$; Cronbach's $\alpha = 0.87$), supporting the evaluation's methodological soundness.

It is important to note what this study does not claim. Because the instrument measures user perceptions of the system rather than cognitive learning outcomes, we do not claim that the application improves vocabulary comprehension or retention; such claims would require a separate quasi-experimental study with pre- and post-tests. Accordingly, our conclusions are confined to the media-characteristic and practicality components of educational R&D.

The findings suggest that immersive VR environments may enhance student engagement with the vocabulary-learning environment and afford contextually situated interaction with household objects, compared with conventional static media. By allowing students to interact directly with virtual objects in contextual settings, the application is designed to support experiential learning; empirical confirmation of learning gains remains a task for future research.

However, this study has several limitations. First, the evaluation was conducted on a limited number of participants ($n = 51$) from a single school, and the analytical approach was confined to descriptive statistics suitable for a practicality evaluation; advanced inferential modeling such as multiple regression or structural equation modeling (PLS-SEM) was not pursued in this study because the EUCS dimensions were treated as parallel facets of user satisfaction rather than as predictor–criterion variables, and a structural model was not part of the study's a priori hypothesis. Second, the study used a quantitative-only user acceptance design; it did not include qualitative triangulation (interviews, classroom observation), so the discussion of device-related latency is a tentative inference rather than a triangulated finding. Third, the study measured user satisfaction rather than learning outcomes. Future research is recommended to (a) include a larger multi-site sample, (b) incorporate a pretest–posttest experimental design with delayed-retention measures to assess vocabulary-acquisition gains, (c) integrate qualitative methods such as semi-structured interviews and classroom observation to triangulate users' perceptions with their actual interaction behavior, and (d) examine the relative predictive contribution of each EUCS dimension toward overall user acceptance using PLS-SEM or multiple regression in a study explicitly designed with a predictor–criterion structural model.

■ DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

During the writing of this manuscript, the author(s) employed generative AI assistants (Claude by Anthropic and ChatGPT by OpenAI) to assist with language refinement, proofreading, and reorganization of structural elements (sub-section ordering, sentence-level clarity, and consistency of terminology). All conceptual content, research design, data collection, data analysis, interpretation of results, and final conclusions are the original work of the authors. The author(s) have reviewed and edited all content generated by these tools and assumed full responsibility for the content of the published article.

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