Virtual Reality (VR) Innovation in Project Based Learning (PjBL) for Teaching English Vocabulary to Elementary Students

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Abstract
The urgency of this research is that the learning process is considered to require exploration and manipulation of objects in visual form to understand concepts. Students have difficulty mastering English due to its abstract and decontextual nature. The purpose of this study is to implement immersive VR with the PjBL model effectively to improve English vocabulary acquisition to understand the relationship between shape and space. The method used is User Experience (UX) Integration of Action Design Research (ADR) with the CII Framework. The number of respondents in this study was 32 students. The results showed a significant effect (Cohen's $d = 3.43$), paired sample t-test results ($t = 14.762$; $p < 0.001$), and an N-Gain score of 0.63. These findings prove that combining immersive VR with the PjBL model effectively improves English vocabulary acquisition, engagement, and student learning experience, and validates the CII framework as a viable approach to technology-enhanced language learning.

1. Introduction

The urgency of this research is crucial for three reasons. First, English vocabulary is considered to require virtual exploration and simulation in the form of visualization to understand abstract concepts (Kamarudin & Zainuddin, 2023; Zhang & Zhao, 2024). English vocabulary is the foundation of global communication, and conventional teaching methods often stagnate in rote memorization, which fails to transfer passive knowledge into active lexical fluency skills. This is a weak point that technology can bridge, suggesting that VR immersive environments are an ideal medium for contextual learning, but there is a methodological gap in formulating effective pedagogical interaction models, especially when integrated with the PjBL framework (Durukan, Artun, & Temur, 2020). Meanwhile, English concepts can be visualized in a 3D perspective, so that students can more easily understand the relationship between form and space. For example, students can explore English vocabulary in a complex 3D virtual environment, so they not only memorize terminology textually, but are also able to construct meaning through direct interaction with objects and understand the spatial relationships between elements in authentic communication scenarios.

However, in reality, VR technology has the ability to create realistic virtual environments, allowing students to interact directly with learning materials in 3D (Alshahrani & Alshammari, 2023; Chen & Tsai, 2022). 3D visualization is very important in English learning, especially for concepts that are difficult to understand through 2D representations (Kuo & Hwang, 2022; Lee & Choi, 2021). On the other hand, VR allows students to interact directly with 3D models, improving spatial, conceptual, personalized, adaptive, and interactive understanding, where the material can be adjusted to the pace and learning style of each student (Tsai & Chai, 2020). Based on this, interactive VR models will form Artificial Intelligence (AI) technology with a User Interface (UI) that supports 3D perspectives. Second, PjBL provides opportunities for students to build knowledge in the real context of English learning. PjBL integrates students' prior knowledge in solving problems and provides space and results that are realized in the form of products relevant to the real world. English is also considered a complex subject to understand, so VR presents a technological complement that can visualize 3D perspectives (Dwino Putra, Rahim, & Saputra, 2022; Zhang & Wang, 2024). VR can help simplify complex concepts with clearer and more understandable visualizations (experiential in nature) (Noviansyah & Sudira, 2020). In an educational context, combining VR with Project-Based Learning (PjBL) can create innovative, immersive, and realistic learning simulations (Aslan & Duruhan, 2019; Hernawan & Sari, 2021). Students not only learn through VR experiences but also engage in challenging, relevant projects, enhancing in-depth understanding and application of knowledge (Huo, Wang, & Zhao, 2023; Lainufar, Mailizar, & Johar, 2021). Therefore, the support of experiential, interactive VR models will significantly impact Project-Based Learning (PjBL) scenarios, enhancing imaginative, artistic, spatial understanding, cognitive skills, and creative thinking patterns.

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Third, the accessibility of VR technology remains limited despite the significant potential of VR integration in Project-Based Learning (PjBL) (Alper & Temur, 2024; Hakkinen, 2023). Many educational institutions, especially in developing countries, face obstacles in adopting VR technology due to high hardware costs and inadequate infrastructure (Graven et al., 2023; Sukirman, Pramudita, Nugroho, & Aminudin, 2023). This creates a gap between schools capable of integrating advanced technology and those that still rely on traditional learning methods. As a result, students in disadvantaged environments miss out on the benefits of the immersive and interactive learning experiences offered by VR (Wang & Chen, 2020). On the other hand, despite this accessibility and understanding challenges, the potential of VR in PjBL remains enormous. This technology can increase student engagement, facilitate collaborative learning, and enable the exploration of complex concepts in a more intuitive manner (Megawati, Shah, Untari, Agustina, & Cahyani, 2023; Ofianto, Ningsih, & Abidin, 2022). This research serves as a strategic bridging node that connects the immersive technology cluster with the PjBL framework, transforming from a passive VR model to a 3D AI-UI-based Interactive VR system that has a strong link strength to increasing students' active lexical fluency (Shofiyah, Untari, & Saputra, 2022; Untari, Hasanah, Kusuma, & Jazuli, 2022; Untari, Wiguna, Andhiarini, & Pratama, 2021). By filling a low-density area in the global literature, this research not only offers experiential pedagogical innovation that mitigates limited school resources but also has policy centrality through collaboration with the Sidoarjo Education Office to support the achievement of the 4th Asta Cita in developing superior human resources towards a Golden Indonesia 2045.

This research positions itself at the forefront of the frontier as a disruptive solution to the stagnation of conventional memorization methods through the integration of Interactive VR and PjBL (Untari, Liansari, & Su'udiah, 2020; Untari, Kamdi, Dardiri, Hadi, & Nurhadi, 2020). More than just a visual simulation, this AI-UI-based model brings to life the experiential construction of meaning to create authentic lexical fluency in students. Based on keyword co-occurrence analysis using VOSviewer (Figure 1), the State of the art of this research is identified in the frontier cluster that connects interactive VR, PjBL, and immersive learning. Bibliometric analysis through VOSviewer empirically shows a significant research gap in the area of English vocabulary mastery which has been trapped in the cluster of conventional methods based on memorization (rotate memorization). Based on the research gap described above, the research objectives can be drawn, namely: The purpose of this study is to implement immersive VR with the PjBL model effectively to improve English vocabulary acquisition to understand the relationship between shape and space.

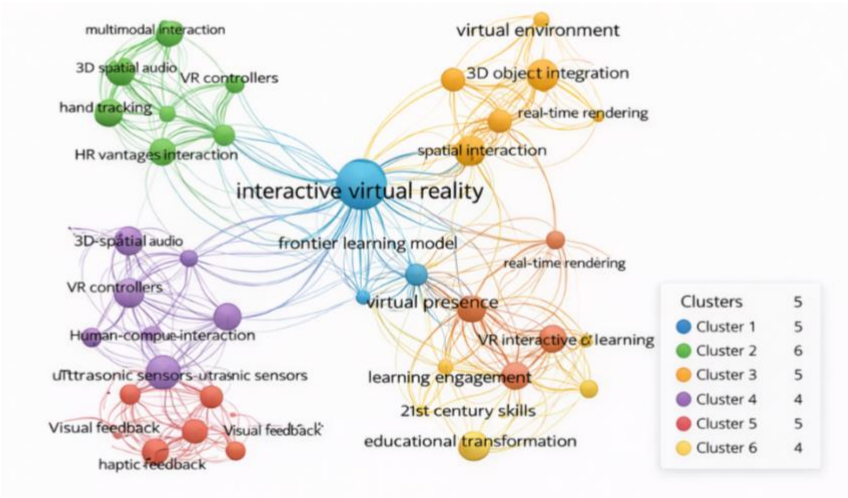

Figure 1. Conceptual Mapping VR

2. Method

The UX-ADR process is implemented as a reflective and iterative design–action–evaluation cycle (Figure 2). The design science method integrates action research to produce IT artifacts through Build-Intervene-Evaluate (BIE), starting from the exploration of user needs and experiences, classroom implementation, and cognitive evaluation to ensure organizational relevance and generalizability of the theory (Herath et al., 2025; Makransky & Petersen, 2021). It is driven by the Cognitive-Immersive Integration (CII) Framework inspired by the Cognitive Affective Model of Immersive Learning (CAMIL) which emphasizes the interaction between VR affordances (immersion and control) and psychological factors such as presence (perceptual dimensions for sensory experience), agency (active interactivity for cognitive empowerment), and sustainability (long-term adoption feasibility through minimizing cognitive load and increasing self-regulation) (Figure 3). This framework guides pedagogical design in a PjBL context, students explore real-world problems such as infrastructure limitations, produce an Immersive-Experience Blueprint (IEB) as an intermediate artifact, and the final output is an adaptive VR model (Johannesson & Perjons, 2022; Nagle et al., 2023; Zolbanin & Aubert,

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2025). This process is validated through mixed-methods data, ensuring increased intrinsic motivation, self-efficacy, and knowledge transfer (Campbell & Stanley, 1963; Creswell & Creswell, 2024; Wang & Zhao, 2024).

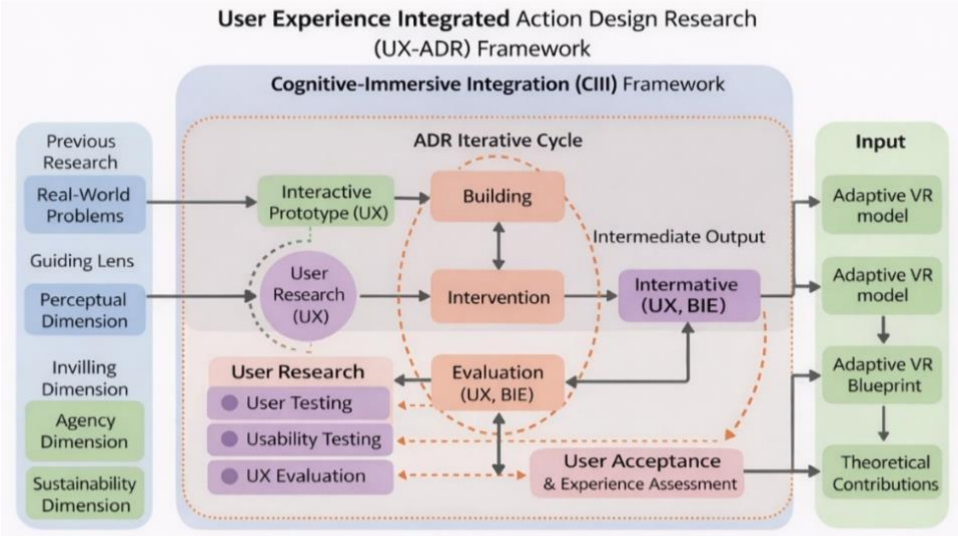

Figure 2. UX-ADR Framework Design Process Flow

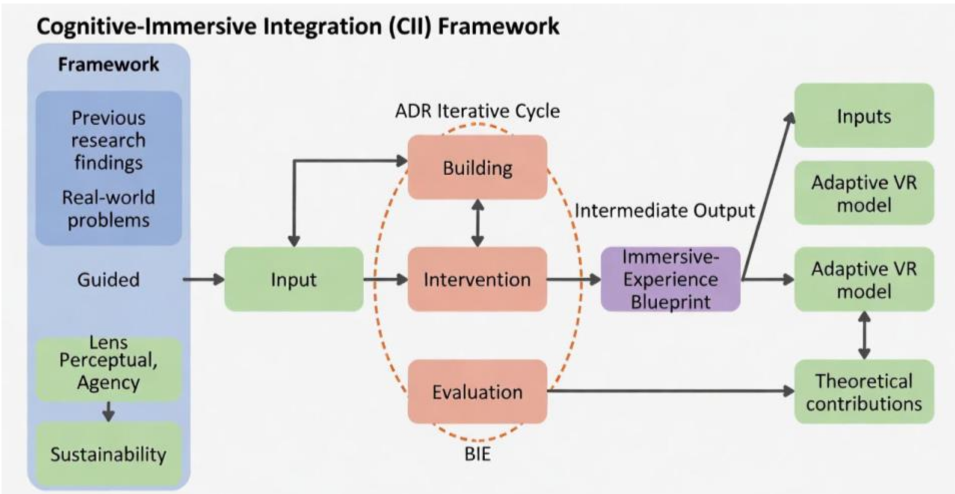

Figure 3. CII Framework

3. Results and Discussion

3.1. Results

The results of the user interface (UI) development in interactive VR show that this media is able to optimally support the user navigation process. The following are the UI results from the English vocabulary VR media that have undergone media validation and substance testing. In the development stage, what is done is the realization of the design into a concrete product, where the transition phase of the conceptual design from the Design stage is realized into a real interactive VR artifact. Activities include content creation, initial testing, and revisions based on feedback to ensure suitability with partners.

Figure 4. User Interface VR English Vocabulary

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3.1.1. Content Validity Index (CVI)

Validation was conducted by three experts: an instructional media expert, an educational technology expert, and an elementary school English language learning expert (see Table 1). The assessment covered aspects of material suitability, learning design, user interface, VR interactivity features, and appropriateness of learning evaluation. The Scale-Level Content Validity Index (S-CVI) value of 0.97 indicates that the Adaptive VR model has a very high level of validity. All indicators scored above the minimum threshold of 0.80, thus declaring the product suitable for implementation in the user trial phase.

Table 1. Expert Content Validity Index

Validation Aspect	I-CVI
Learning Content	1.00
Learning Objectives	1.00
User Interface Design	0.92
Navigation System	0.92
Interactive Features	1.00
Project-Based Learning Integration	0.92
Assessment Components	1.00

Average S-CVI = 0.97

3.1.2. Usability Testing (System Usability Scale)

Usability testing was conducted on 32 elementary school students after using the VR system for four meetings (see Table 2). The measurement results showed an average SUS score of 88.13. Based on Bangor et al.'s interpretation, this value is included in the Excellent category and is at Grade A. These results indicate that students can use the system easily, understand navigation well, and experience few obstacles during the learning process.

Table 2. System Usability Scale Results

Indicator	Score
SUS Mean Score	88.13
SUS Grade	A
Acceptability	Excellent
Adjective Rating	Best Imaginable

3.1.3. User Experience Questionnaire (UEQ)

User experience evaluation was conducted using the six main dimensions of UEQ (see Table 3). The average score for all dimensions was above 2.00, which is considered Excellent based on the UEQ benchmark. The highest scores were found in the Novelty (2.87) and Stimulation (2.79) dimensions, indicating that students experienced a new, engaging, and motivating learning experience.

Table 3. UEQ Results

Dimension	Mean Score
Attractiveness	2.64
Perspicuity	2.51
Efficiency	2.43
Dependability	2.38
Stimulation	2.79
Novelty	2.87

3.1.4. Learning Outcome Analysis

Analysis of learning outcomes was conducted using tests of basic vocabulary mastery and simple English phrases before and after VR implementation (see Table 4). The results show an average score increase of the following: 85.47 − 60.84 = 24.63 points. This improvement shows that the use of Adaptive VR is able to help students understand vocabulary more effectively than conventional learning.

Table 4. Descriptive Statistics of Learning Outcomes

Test	N	Mean	SD
Pre-test	32	60.84	8.21
Post-test	32	85.47	6.12

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3.1.5. N-Gain Score Analysis

The effectiveness of improving learning outcomes was analyzed using the N-Gain Score (see Table 5). An N-Gain value of 0.63 indicates that the implementation of Adaptive VR is in the moderate to high effectiveness category. These results indicate that immersive technology significantly contributes to improving students' vocabulary mastery.

Table 5. N-Gain Score

Indicator	Value
Average N-Gain	0.63
Category	Medium-High

3.1.6. Paired Sample t-Test

The paired t-test was used to determine the significance of differences in learning outcomes before and after treatment (see Table 6). A significance value of 0.000 (<0.05) indicates a significant difference between pre-test and post-test scores. Thus, the use of Adaptive VR has been statistically proven to improve elementary school students' English vocabulary mastery.

Table 6. Paired Sample t-Test Results

Variable	Mean Difference	t-value	Sig. (2-tailed)
Pretest–Posttest	24.63	14.762	0.000

3.1.7. Effect Size (Cohen's d)

To determine the magnitude of the influence of the implementation of Adaptive VR, Effect Size calculations were carried out using Cohen's d (see Table 7). Cohen's d value of 3.43 indicates a Very Large Effect. This result confirms that the increase in vocabulary skills was not only statistically significant but also had a significant practical impact on the learning process.

Table 7. Effect Size Analysis

Variable	Cohen's d	Interpretation
Pretest–Posttest	3.43	Very Large Effect

3.2. Discussion

The research results show that the Adaptive VR model developed using the UX-ADR approach has a very high level of feasibility. This is demonstrated by the S-CVI value of 0.97, indicating a strong level of agreement among experts regarding the suitability of the material, learning design, system interactivity, and integration of Project-Based Learning (PjBL) within the virtual environment (Knoblauch, 2022). The high validity value indicates that the learning design meets the principle of alignment between learning objectives, learning activities, and evaluation, which is the main foundation for developing technology-based learning media (Hidayah, Kuswanto, Jumadi, & Khotimah, 2024).

These findings demonstrate that the Cognitive-Immersive Integration (CII) framework successfully bridges pedagogical needs with the characteristics of VR technology. Within this framework, the dimensions of perceptual presence, agency, and sustainability function not only as elements of technological design but also as cognitive mechanisms that enable students to actively construct meaning through immersive learning experiences (Lin, 2018). These results reinforce the view that the effectiveness of educational technology is not solely determined by technological sophistication, but rather by the compatibility between the technology and the instructional design used (Jaiswal, Karabiyik, Thomas, & Magana, 2018).

In terms of system usability, the System Usability Scale (SUS) score of 88.13 indicates that Adaptive VR is in the Excellent category and Grade A. This score is well above the average SUS score of 68, which is generally used as the threshold for system acceptance. This result shows that there were no major challenges for students to comprehend the navigation, features, and user flow of the system. This finding is especially significant in the context of primary school education since the application of digital innovation is sometimes hampered by high levels of technological complexity. According to research on the SUS, users' opinions that the system is simple to use, straightforward to understand, and facilitates efficient work completion are reflected in high scores. In addition to usability, this study discovered a very favorable user experience.

These results are in line with several UEQ research that show how important the stimulation and novelty dimensions are for encouraging user engagement and sustaining use of digital learning systems. Between the pre-test and the post-test, the average score for learning outcomes rose from 60.84 to 85.47. This 24.63-point

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improvement shows that students' language comprehension improved after using Adaptive VR. These findings suggest that contextual learning experiences and three-dimensional visualization can assist students in making connections between words, objects, and meanings more successfully than conventional memorizing techniques.

These results are consistent with studies on immersive technology-based vocabulary acquisition, which demonstrate how virtual environments can enhance student engagement, vocabulary retention, and comprehension. Vocabulary scores increased from 61.56 to 83.20 following the intervention, a statistically significant difference, according to a study on the application of augmented reality in primary school kids. The researchers came to the conclusion that immersive and interactive learning opportunities can enhance vocabulary knowledge while also fostering a more pleasurable learning environment.

High scores on both dimensions indicate that students experienced a different learning experience compared to conventional learning. A more interesting and significant learning experience was produced by the three-dimensional virtual environment, direct interaction with vocabulary objects, and the incorporation of real-world context-based initiatives. These findings are consistent with a number of UEQ studies that demonstrate the significance of the stimulation and novelty dimensions in fostering user engagement and maintaining use of digital learning systems.

The average score for learning outcomes increased from 60.84 in the pre-test to 85.47 in the post-test. Students' language comprehension improved after using Adaptive VR, as demonstrated by a 24.63-point increase. These findings imply that contextual learning experiences and three-dimensional visualization can help students connect words, objects, and meanings more effectively than traditional memorization strategies.

These findings are consistent with previous research on immersive technology-based vocabulary acquisition, which has shown how virtual environments can improve student engagement, vocabulary retention, and comprehension. A study on the use of augmented reality in primary school children found that vocabulary scores increased from 61.56 to 83.20 as a result of the intervention, a statistically significant difference. The researchers concluded that immersive and interactive learning experiences can improve vocabulary knowledge while also creating a more pleasant learning environment. This study's findings are also consistent with previous research on VR in primary school English instruction, which shows that VR use enhances students' vocabulary achievement as well as affective characteristics including learning interest, self-confidence, and involvement in the learning process.

This achievement can be explained by the embodied learning hypothesis, which argues that the learning process is more effective when students engage physically and sensorially in the learning experience rather than only orally receiving information. VR environments enable students to engage directly with visual representations of objects, resulting in the integration of visual perception, motor actions, and cognitive processing. Recent study on immersive learning shows that physical contact and sensory experiences in virtual worlds can improve conceptual understanding and memory retention compared to standard screen-based learning.

The N-Gain value of 0.63, which falls within the medium-high range, adds to the learning efficacy. This statistic shows that Adaptive VR has strong learning benefits. In elementary education, this accomplishment is crucial since vocabulary mastery is a fundamental basis for learning English. A robust vocabulary will have an impact on following learning stages such as reading, writing, speaking, and listening. The Paired Sample t-Test yielded a t-value of 14.762 ($p < 0.001$), demonstrating a significant difference in learning outcomes before and after VR installation. This statistical significance implies that the improvement in learning outcomes was not due to chance but rather was a direct result of the interventions. This finding is supported by the Effect Size (Cohen's d) value of 3.43, which is in the extremely big effect category. In educational research, an effect size value greater than 0.80 is regarded large, so a score of 3.43 suggests that Adaptive VR has a significant impact on vocabulary mastery.

This substantial effect size suggests that the benefits of VR go beyond motivation and have a considerable impact on students' cognitive ability. In other words, VR technology not only makes studying more exciting, but it also helps students acquire and remember English language (Nguyen et al., 2023). This finding reinforces numerous studies that suggest that immersive technology provides an opportunity to transform learning from a passive activity into an active, contextual, and learner-centered learning experience (Kokotsaki, Menzies, & Wiggins, 2016).

Overall, the results of this study provide an empirical contribution to the development of Cognitive-Immersive Integration (CII) theory. The findings show that the amount of immersion influences the success of VR-based learning, as does the interplay between user perception of the system (usability), user experience, and the potential to gain knowledge through authentic project activities. Thus, the Adaptive VR model created through UX-ADR can be positioned as an innovative learning model capable of addressing the challenges of

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English learning in elementary schools while also supporting the transformation of digital education towards more adaptive, personalized, and meaningful learning (Ambiyar, Wulansari, Dewi, Ananda, & Zumroh, 2024; Cummings et al., 2022; Shneiderman, 2020).

4. Conclusion

This research successfully developed an Artificial Intelligence-User Interface (AI-UI)-based Adaptive VR integrated with Project-Based Learning (PjBL) using the User Experience-Action Design Research (UX-ADR) approach and the Cognitive-Immersive Integration (CII) Framework for learning basic English vocabulary and simple phrases for elementary school students. These results show that Adaptive VR can give students a high level of motivation and an interesting, user-friendly educational experience. Engaging, easy-to-use learning environment. Additionally, the use of adaptive VR has been successful in raising student learning results. Practically, Adaptive VR can be an innovative alternative in English learning in elementary schools, addressing the limitations of conventional memorization methods through more contextual, interactive, and student-centered learning experiences. Thus, the developed model has the potential for broader implementation as part of the digital learning transformation and strengthening of 21st-century competencies in elementary education settings.

Author Contributions

Rahmania Sri Untari: Conceptualization, Methodology, Project Administration, Funding Acquisition, Investigation, Formal Analysis, Validation, Writing – Original Draft, Writing – Review & Editing. Yuli Astutik: Investigation, Data Curation, Resources, Validation, Writing – Review & Editing. Akbar Wiguna: Software Development, Visualization, Data Curation, Validation. Bobur Sabirov: Supervision, Methodology, Formal Analysis, Validation, Writing – Review & Editing.

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Declaration of Conflicting Interests

All writers must state any financial or personal links with other individuals or organizations that may inappropriately affect (bias) their work. Employment, consulting, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding are all examples of potentially clashing interests.

Data Availability

The datasets generated during this study, including expert validation data, System Usability Scale (SUS) results, User Experience Questionnaire (UEQ) responses, pre-test and post-test scores, and supporting documentation related to the development of the Adaptive VR learning model, are available from the corresponding author upon reasonable request. Access to the data is subject to institutional and ethical considerations regarding participant privacy.

Declaration on AI Use

The authors used artificial intelligence (AI)-assisted tools exclusively for language editing, grammar correction, and manuscript readability enhancement under careful human supervision. AI tools were not used to generate research ideas, study design, data collection, data analysis, interpretation of results, conclusions, or scholarly insights. All intellectual content and final decisions remain the sole responsibility of the authors.

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References

Alper, A., & Temur, A. (2024). Advancing VR edutainment design in blended learning: Learners' experiences. *Journal of Educational Technology & Society*.

Alshahrani, S., & Alshammari, M. (2023). Exploring the effect of virtual reality on students' learning in science education. *International Journal of Educational Technology in Higher Education, 20*(1), 1–15.

ISSN: 2797-3174

Ambiyar, A., Wulansari, R. E., Dewi, F. K., Ananda, Y. F., & Zumroh, Z. (2024). Trends of project based learning in engineering education from 2008 to 2023: A systematic literature review approach. *Jurnal Pendidikan Tambusai, 8*(1), 6328–6337.

Aslan, S. A., & Duruhan, K. (2019). The effect of problem based learning approach in information technologies and software course on academic achievement of students. *Çukurova Üniversitesi Eğitim Fakültesi Dergisi, 48*(1), 32–72.

Campbell, D. T., & Stanley, J. C. (1963). *Experimental and quasi-experimental designs for research*. Houghton Mifflin.

Chen, C. H., & Tsai, C. C. (2022). The role of virtual reality in science education: A systematic review. *Educational Technology & Society, 25*(1), 45–60.

Creswell, J. W., & Creswell, J. D. (2024). *Research design: Qualitative, quantitative, and mixed methods approaches* (6th ed.). SAGE Publications.

Durukan, A., Artun, H., & Temur, A. (2020). Virtual reality in science education: A descriptive review. *Journal of Science Learning, 3*(3), 132–142. https://doi.org/10.17509/jsl.v3i3.21906

Dwino Putra, F. A., Rahim, S. E., & Saputra, Z. R. (2022). Practical learning based on virtual reality methods as a solution to increase evaluation level 1 results in practical learning at PT PLN (Persero) UPDL Palembang. *Atlantis Press*. https://doi.org/10.2991/ahe.k.220205.018

Graven, M., et al. (2023). Classifying and modeling secondary students' active learning in a VR environment. *Computers & Education*.

Häkkinen, P. (2023). Virtual reality in education: Focus on the role of emotions and physiological reactivity. *Journal for Virtual Worlds Research*.

Hernawan, A., & Sari, D. (2021). The effect of project based learning with virtual media on student learning outcomes. *International Journal of Emerging Technologies in Learning, 16*(3), 1–10.

Hidayah, M. U., Kuswanto, H., Jumadi, & Khotimah, K. (2024). Project-based learning on science process skills and learning outcomes in high school physics: A quasi-experimental study on the topic of fluids. *Journal of Education Research and Evaluation, 8*(1), 1–10.

Huo, Y., Wang, A., & Zhao, Y. (2023). PBL-based VR course for preservice teachers' designing skills in applied university under coronavirus. *Interactive Learning Environments, 31*(6), 3647–3663. https://doi.org/10.1080/10494820.2021.1939061

Jaiswal, A., Karabiyik, T., Thomas, P., & Magana, A. J. (2021). Characterizing team orientations and academic performance in cooperative project-based learning environments. *Education Sciences, 11*(9), 520. https://doi.org/10.3390/educsci11090520

Johannesson, P., & Perjons, E. (2022). Towards a scheme for contribution in action design research. In *Design Science Research in Information Systems and Technology: DESRIST 2022* (pp. 376–387). Springer. https://doi.org/10.1007/978-3-031-06516-3_28

Kamarudin, M. K., & Zainuddin, N. (2023). The effectiveness of virtual reality in enhancing science learning: A meta-analysis. *International Journal of Science Education, 45*(2), 123–145.

Knoblauch, C. (2022). Combining and balancing project-based and blended learning in education. *International Journal of Advanced Corporate Learning, 15*(1), 35–44. https://doi.org/10.3991/ijac.v15i1.27135

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools, 19*(3), 267–277. https://doi.org/10.1177/1365480216659733

Kuo, Y. C., & Hwang, G. J. (2022). A review of the effectiveness of virtual reality in science education: A meta-analysis. *Educational Research Review, 34*, 100–115.

Lainufar, Mailizar, & Johar, R. (2021). Exploring the potential use of GeoGebra augmented reality in a project-based learning environment: The case of geometry. *Journal of Physics: Conference Series, 1882*(1), 1–8. https://doi.org/10.1088/1742-6596/1882/1/012045

Lee, J. H., & Choi, H. (2021). The effect of virtual reality on learning outcomes in science education: A meta-analysis. *Journal of Educational Psychology, 113*(3), 456–470.

Lin, C. L. (2018). The development of an instrument to measure the project competences of college students in online project-based learning. *Journal of Science Education and Technology, 27*(1), 57–69. https://doi.org/10.1007/s10956-017-9708-y

Liu, M., & Chen, Y. (2021). Enhancing student engagement in science learning through virtual reality: A case study. *Journal of Science Education and Technology, 30*(4), 456–467.

Makransky, G., & Petersen, G. B. L. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational Psychology Review, 33*, 937–958. https://doi.org/10.1007/s10648-020-09586-2

Megawati, F., Shah, S. S., Untari, R. S., Agustina, S., & Cahyani, C. R. (2023). Students' vocabulary learning through augmented reality (AR): EFL student teachers' perceptions. *Academia Open, 8*(2). https://doi.org/10.21070/acopen.8.2023.7006

Nagle, T., Birkbeck, G., Daly, N., Jones, S., O'Sullivan, J., & Sammon, D. (2023). Methodological learning-by-doing for action design research. *Journal of Information Systems Education, 34*(3), 293–306. https://aisel.aisnet.org/jise/vol34/iss3/4

Noviansyah, W., & Sudira, P. (2020). The praxis of project-based learning at PIKA Vocational Secondary School Semarang. *Jurnal Pendidikan Vokasi, 10*(1), 1–10. https://doi.org/10.21831/jpv.v10i1.29032

ISSN: 2797-3174

Ofianto, A., Ningsih, T. Z., & Abidin, N. F. (2022). The development of historical thinking assessment to examine students' skills in analyzing the causality of historical events. *European Journal of Educational Research, 11*(2), 609–619. https://doi.org/10.12973/eu-jer.11.2.609

Shneiderman, B. (2020). Human-centered artificial intelligence: Reliable, safe & trustworthy. *International Journal of Human-Computer Interaction, 36*(6), 495–504. https://doi.org/10.1080/10447318.2020.1741118

Shofiyah, N., Untari, R. S., & Saputra, Y. E. A. (2022). Designing Android based mobile application for earth learning at junior high school. *Jurnal Ilmu Pendidikan, 28*(1), 37–43. https://doi.org/10.17977/um048v28i1p37-43

Sukirman, D. A., Pramudita, D. A., Nugroho, A. A., & Aminudin, M. R. (2023). Educational game for learning computational thinking in a low budget virtual reality environment. *Undiksha Journal of Education, 15*(1), 1–10. https://doi.org/10.23887/janapati.v12i1.52743

Tsai, C. C., & Chai, C. S. (2020). The role of virtual reality in science education: A systematic review. *Journal of Science Education and Technology, 29*(5), 123–135.

Untari, R. S., Hasanah, F. N., Kusuma, M. D., & Jazuli, M. I. (2022). Pengembangan augmented reality (AR) berbasis Android pada pembelajaran pemodelan bangun ruang 3D. *Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan, 7*(5), 190–196. https://doi.org/10.17977/2502-471X.2475

Untari, R. S., Kamdi, W., Dardiri, A., Hadi, S., & Nurhadi, D. (2020). The development and application of interactive multimedia in project based learning to enhance students' achievement for 2D animation making. *International Journal of Emerging Technologies in Learning, 15*(16), 17–30. https://doi.org/10.3991/ijet.v15i16.16521

Untari, R. S., Liansari, V., & Su'udiah, F. (2020). Open Problem Based Learning (OPBL) scenario on 2D text animation using Polya approach. *Jurnal Ilmu Pendidikan, 26*(1), 22–28. https://doi.org/10.17977/um048v26i1p22-28

Untari, R. S., Wiguna, A., Andhiarini, R. M., & Pratama, A. F. (2021). Android-based educational games for online learning at kindergarten. *Jurnal Ilmu Pendidikan, 27*(2), 81–85. https://doi.org/10.17977/um048v27i2p81-85

Wang, F., & Chen, Y. (2020). Virtual reality and augmented reality in education: A review of recent advances. *Computers & Education, 159*, 104–120.

Wang, P., & Zhao, Z. (2024). The effectiveness of virtual reality-based training on employee performance: A quasi-experimental study. *Journal of Business and Psychology, 39*(4), 689–701.

Yang, Y., & Chen, Y. (2023). The impact of virtual reality on student engagement in science learning: A meta-analysis. *Computers & Education, 180*, 104–120.

Zhang, L., & Wang, Y. (2024). Enhancing science learning through virtual reality: A systematic review. *International Journal of Science Education, 46*(1), 1–20.

Zhang, Y., & Zhao, Y. (2024). The impact of virtual reality on learning outcomes in science education: A review. *Journal of Educational Computing Research, 62*(1), 1–20.

Zolbanin, H., & Aubert, B. (2025). A process model for design-oriented machine learning research in information systems. *The Journal of Strategic Information Systems, 34*(1), 101868. https://doi.org/10.1016/j.jsis.2024.101868

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