RESEARCH ARTICLE

# Comparative Study on the Effectiveness of Interactive Virtual Reality Simulations Integrating Acehnese Local Wisdom for Mobile-Based Problem-Based Learning

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**Abstract**

Technological advancements have transformed educational practices worldwide. Interactive virtual reality simulations incorporating Acehnese local wisdom represent an emerging educational approach with significant potential. The research examines learning effectiveness enhancement through engaging technology integration, application of Acehnese cultural elements in educational settings, development of interactive problem-based learning environments, and evaluation of effectiveness differences between virtual reality implementations and traditional teaching methods. Virtual reality technology creates immersive environments where users experience simulated settings with realistic interaction capabilities. Acehnese wisdom elements integrated into these environments facilitate deeper cultural understanding among students. The problem-based learning framework encourages collaborative problem-solving through peer engagement and discussion. Research outcomes aim to establish more engaging instructional methodologies while promoting appreciation of Acehnese heritage. The comparative analysis between virtual reality implementations and conventional approaches reveals essential information regarding technological applications in educational contexts. Results demonstrate that virtual reality simulations incorporating Acehnese cultural elements offer innovative solutions for problem-based learning environments, substantially improving student engagement metrics and learning outcome measurements.

**Keywords**

Interactive Virtual Reality Simulation; Acehnese Local Wisdom; Problem-Based Learning; Learning Effectiveness; Comparative Study.

# 1 | INTRODUCTION

Educational technology utilization has experienced substantial growth, particularly regarding software development and technology-based learning systems (Wali & Ahmad, 2017). Computer Assisted Learning (CAL) stands among prominent educational technologies, demonstrating significant capacity for enhancing learning effectiveness through interactive media engagement (Ahmad & Wali, 2019; Wali & Ahmad, 2021; Ahmad *et al.*, 2020). Educational innovations extending to Android applications and animation techniques have emerged as effective learning media, particularly within early childhood educational contexts (Muhammad & Ahmad, 2020; Ahmad & Al Bahri, 2020; Maulana *et al.*, 2021). Despite technological advancement, a critical need persists for integrating cultural heritage elements into educational technology development frameworks. Aceh's rich cultural traditions represent valuable educational resources with potential for captivating learning experiences. Research examining Acehnese cultural wisdom application within technology-enhanced learning environments remains essential, specifically concerning interactive virtual reality simulation implementation for improving student engagement and learning effectiveness measurements. Comparative analysis examining innovative technology effectiveness against conventional methodologies provides critical information for educational practice advancement. Research development focusing on effective learning technologies benefits Indonesian students across educational levels. The current study addresses multiple dimensions of problem-based learning implementation using virtual reality simulations within Acehnese educational contexts. Research questions examine cultural wisdom integration processes, effectiveness comparisons between technology-enhanced and conventional learning approaches, student response patterns toward technological implementations, development challenges, and implementation enhancement strategies. Methodological approaches compare learning effectiveness between virtual reality simulations incorporating Acehnese cultural elements and traditional instructional methods. Research outcomes contribute toward innovative educational technology development within Acehnese contexts while leveraging cultural heritage as engaging learning resources.

Interactive virtual reality simulation incorporating Acehnese cultural wisdom represents the primary innovative approach within problem-based learning environments. Virtual reality technology enables student interaction with simulated environments resembling authentic contexts, facilitating learning and problem-solving activities within controlled settings. Acehnese cultural wisdom integration within learning processes promotes deeper understanding and appreciation for regional cultural heritage. Problem-based learning environments structured for engagement and interactivity enhance student participation. Educational effectiveness improvement through innovative technology integration represents a central research objective. Comparative assessment evaluating virtual reality simulation effectiveness against conventional approaches provides essential data regarding educational outcomes. The proposed approach offers potential solutions for enhancing student engagement and learning effectiveness within contemporary educational frameworks. Virtual reality simulations create engaging learning environments that enhance student involvement and material comprehension. Cultural wisdom integration enriches educational experiences while providing contextual relevance. Comparative effectiveness analysis between technological and conventional approaches establishes research novelty. Interactive virtual reality technology facilitates effective and efficient learning processes across educational domains. Previous research demonstrates technology applications across diverse fields including physical training (Yang, 2018), cardiopulmonary resuscitation instruction (Almousa *et al.*, 2019), and international collaborative simulation design (D'Errico, 2021). Educational technology research continues advancing through various implementations (Su & Cheng, 2019).

Educational technology development includes e-learning module implementation based on Learning Management Systems for interactive media applications (Yetti & Ahyanuardi, 2020). Metaverse applications for interactive learning environments represent emerging educational approaches (Rachmadtullah *et al.*, 2022). Library innovation through augmented and virtual reality implementation addresses Generation Z learning preferences (Aulianto, 2020). Interactive virtual reality design at university settings demonstrates institutional technology adoption (Kaloh *et al.*, 2022). Virtual reality applications enhance interactive learning experiences, enabling experimental activities and simulations within controlled environments (Hartono). Technology implementation improves student understanding while developing practical skills (Kertati *et al.*, 2023). Virtual reality creates immersive learning experiences while facilitating remote educational access (Salamun *et al.*, 2021). Educational technology innovation remains essential within contemporary digital educational contexts. Research novelty emerges through Acehnese cultural wisdom integration within virtual reality learning environments, enriching educational experiences while promoting cultural understanding and appreciation. Comparative analysis examining virtual reality simulation effectiveness against conventional approaches provides valuable educational insights. Virtual reality technology represents significant educational innovation with demonstrated capacity for enhancing learning quality across educational domains. Research applications span physical training, medical education, chemistry laboratory simulations, e-learning development, metaverse integration, library enhancement, and biotechnology instruction. The current research contributes toward educational technology advancement within digital transformation.

Educational technology development continues transforming learning environments through immersive experiences and interactive engagement opportunities. Virtual reality applications provide realistic simulations where students actively participate rather than passively receiving information. Cultural wisdom integration establishes connections between technological innovation and traditional knowledge systems, creating balanced educational approaches. Problem-based learning frameworks encourage critical thinking development through collaborative engagement with authentic challenges. Technology-enhanced learning environments facilitate personalized educational experiences addressing diverse learning preferences and abilities. Comparative research methodologies provide empirical evidence regarding educational effectiveness across instructional approaches. Research outcomes inform educational policy development and instructional design practices within contemporary learning environments. Virtual reality implementation challenges include technology access considerations, professional development requirements, and curriculum integration strategies. Educational technology adoption requires systematic approaches addressing technical, pedagogical, and administrative dimensions. Research examining virtual reality applications within culturally-relevant educational contexts contributes toward comprehensive understanding of technology effectiveness across diverse learning environments.

## 2 | BACKGROUND THEORY

In contemporary educational landscapes, technological integration has emerged as a transformative force reshaping pedagogical approaches and learning environments. This evolution manifests prominently in software development and technology-enhanced learning systems (Wali & Ahmad, 2017). Computer Assisted Learning (CAL) represents a significant advancement, leveraging interactive media to substantially improve educational effectiveness (Ahmad & Wali, 2019; Wali & Ahmad, 2021; Ahmad *et al*., 2020). Educational innovation has expanded to include Android applications and animation technologies as engaging instructional media, particularly within early childhood education contexts (Muhammad & Ahmad, 2020; Ahmad & Al Bahri, 2020; Maulana *et al*., 2021). Despite technological proliferation, a critical imperative remains for integrating indigenous knowledge systems into educational technology frameworks. Aceh's cultural heritage presents an extraordinarily rich resource for developing engaging and culturally responsive learning experiences. This recognition necessitates comprehensive research exploring Acehnese cultural wisdom applications within technology-enhanced learning environments, with particular emphasis on interactive virtual reality simulation implementation. These immersive technologies demonstrate significant potential for enhancing student engagement metrics and learning effectiveness outcomes. Cultural wisdom integration within technology-enhanced learning environments creates opportunities for developing deeper cultural understanding and appreciation among learners. This approach aligns with global educational technology trends while simultaneously ensuring cultural preservation and transmission across generations.

The current research investigates methodologies for seamlessly integrating Acehnese cultural elements within interactive virtual reality simulations, creating immersive and culturally enriched learning experiences. Comparative analysis examining innovative technology effectiveness against conventional instructional methodologies provides essential information regarding differential impacts on student learning outcomes. This investigation illuminates respective strengths and limitations across methodological approaches, offering insights regarding potential benefits associated with technological integration within educational contexts. Research significance extends beyond regional considerations, with findings informing beneficial learning technology development throughout Indonesian educational systems. By examining complex relationships between technology implementation, cultural wisdom integration, and pedagogical approaches, this research contributes to broader discourse concerning innovative educational practices in contemporary learning environments. The research methodology employs an innovative problem-solving approach through interactive virtual reality simulations incorporating Acehnese cultural wisdom as an enhancement strategy for problem-based learning environments. These simulation technologies enable learners to interact with virtual environments closely resembling authentic contexts, facilitating experiential learning opportunities and problem-solving activities within controlled settings. Acehnese cultural wisdom integration represents a deliberate strategy for developing deeper cultural understanding and appreciation, creating holistic and enriched learning experiences for students across educational levels.

Problem-based learning approaches integrated with innovative technology implementation create engaging learning environments fostering critical thinking development and collaborative skills among participants. Through structured learning activities, students actively pursue solutions to authentic challenges through collaborative discussions and group problem-solving exercises. Cultural wisdom integration introduces unique perspectives to problem-solving processes, enriching learning experiences while broadening student perspectives beyond conventional educational frameworks. This innovative approach enhances learning effectiveness through

interactive technology engagement while promoting cultural inclusivity within educational contexts, creating relevant and meaningful learning experiences for diverse student populations. Interactive simulations and virtual reality technologies demonstrate significant capacity for creating engaging learning environments that enhance student participation and conceptual understanding. Acehnese cultural wisdom integration further enriches these experiences by providing distinctive cultural perspectives throughout the learning process. Research novelty emerges through systematic integration of Acehnese cultural elements within virtual reality learning environments and comparative effectiveness analysis between innovative technology implementation and conventional instructional methodologies.

Virtual reality simulation applications have demonstrated effectiveness across diverse educational domains including physical training programs, medical education contexts, and international collaborative design initiatives. This research contributes to expanding knowledge regarding potential benefits and implementation challenges associated with virtual reality technology in educational settings. Previous research examining e-learning module development based on Learning Management Systems (Yetti & Ahyanuardi, 2020), metaverse applications for interactive learning (Rachmadtullah *et al.*, 2022), and library innovation through augmented and virtual reality implementation (Aulianto, 2020) has established foundational understanding regarding educational technology integration. The incorporation of Acehnese cultural wisdom within virtual reality simulations represents a significant contribution to educational technology research, enriching learning experiences through cultural contextualization. This pioneering approach utilizes advanced technology for preserving and promoting indigenous knowledge while simultaneously enhancing problem-based learning effectiveness. Research findings contribute to ongoing discourse examining intersections between technology implementation, cultural preservation, and educational innovation, with implications extending beyond immediate Acehnese contexts to broader educational applications.

Virtual reality technologies create immersive learning environments where students actively engage with educational content rather than passively receiving information. These environments facilitate experiential learning opportunities through realistic simulations of phenomena that might otherwise remain inaccessible within conventional classroom settings. The technology enables visualization of abstract concepts, making complex ideas more comprehensible through interactive engagement. Cultural wisdom integration establishes meaningful connections between technological innovation and traditional knowledge systems, creating balanced educational approaches respecting indigenous perspectives while embracing technological advancement. Problem-based learning frameworks within virtual reality environments encourage critical thinking development through engagement with authentic challenges reflecting real-world complexity. These approaches promote collaborative problem-solving skills essential for professional success in contemporary workplaces. Technology-enhanced learning environments facilitate personalized educational experiences addressing diverse learning preferences and abilities, allowing students to progress at individualized paces while receiving immediate feedback regarding performance outcomes.

Educational effectiveness enhancement through virtual reality implementation includes improved knowledge retention through multisensory engagement, increased motivation through gamification elements, and development of spatial understanding through three-dimensional representation capabilities. Cultural elements integration creates contextual relevance connecting abstract concepts with familiar cultural frameworks, enhancing material comprehension while promoting cultural appreciation. The immersive nature of virtual reality creates emotional engagement with learning content, strengthening memory formation and concept internalization processes. Implementation challenges include technology access considerations across diverse socioeconomic contexts, professional development requirements for educators, and curriculum integration strategies ensuring alignment with educational standards. Effective implementation requires systematic approaches addressing technical infrastructure requirements, pedagogical framework development, and administrative support systems. Research examining virtual reality applications within culturally-relevant educational contexts contributes toward comprehensive understanding of technology effectiveness across diverse learning environments while informing future educational technology development initiatives. The integration of Acehnese cultural wisdom within virtual reality simulations represents an innovative approach preserving cultural heritage while enhancing educational effectiveness. This research provides valuable insights regarding technology implementation strategies, cultural integration methodologies, and comparative effectiveness measurements. Findings contribute toward developing culturally responsive educational technologies addressing contemporary learning needs while honoring traditional knowledge systems. Through systematic investigation of these interconnected elements, the research advances understanding regarding effective educational practices within increasingly digital learning environments.

## 3 | METHOD

This research employs a structured methodology to comprehensively investigate the integration of interactive virtual reality simulations enriched with Acehnese cultural wisdom into problem-based learning environments. The methodological approach begins with an extensive literature review examining interactive virtual reality applications, Acehnese cultural traditions, and problem-based learning frameworks. This comprehensive examination of relevant journals, academic publications, and pertinent documents establishes the theoretical foundation supporting subsequent research activities. Scholarly resources provide critical insights regarding existing research gaps while informing methodological design decisions throughout the investigation process. The research implements a quantitative approach utilizing experimental methods to compare effectiveness between interactive virtual reality simulations incorporating Acehnese cultural elements and conventional instructional approaches. The study adopts a Randomized Controlled Trial (RCT) with Pretest-Posttest Control Group Design, providing robust framework for systematic investigation while controlling potential confounding variables. This experimental design enables precise measurement of intervention effects through comparison between treatment and control conditions, establishing causal relationships between instructional approaches and learning outcomes. The research targets high school students in Aceh as the primary population, with 100 participants randomly selected from various regional institutions through random sampling techniques. This sampling approach ensures representative participant diversity while minimizing selection bias that might otherwise compromise research validity.

Data collection procedures implement multiple instruments including standardized written assessments and semi-structured interviews with selected participants. Written assessments measure subject matter comprehension across both experimental and control conditions, providing quantitative metrics for comparative analysis. Semi-structured interviews generate qualitative insights regarding student perceptions, experiences, and responses toward different instructional methodologies. This mixed-methods approach enables comprehensive understanding of both performance outcomes and experiential dimensions associated with different learning environments. Collected data undergoes rigorous statistical analysis using SPSS software, employing Analysis of Variance (ANOVA) or t-test procedures depending on specific distribution characteristics. These analytical techniques test research hypotheses while assessing comparative effectiveness between virtual reality implementation and conventional instructional approaches regarding subject matter comprehension and engagement metrics. Following data analysis completion, the research proceeds to prototype development and model design phases based on analytical findings. This stage involves creating functional virtual reality simulation prototypes incorporating Acehnese cultural elements within problem-based learning frameworks. The development process follows established software development methodologies including spiral or prototyping models, ensuring systematic and iterative refinement through continuous feedback integration. Feasibility assessment evaluates prototype effectiveness across multiple dimensions including technical functionality, user experience characteristics, and educational impact measurements. This comprehensive evaluation provides essential information regarding implementation viability within authentic educational contexts.

The research culminates with conclusion development and recommendation formulation based on comprehensive analysis of collected data. Conclusions address comparative effectiveness between interactive virtual reality simulations incorporating Acehnese cultural elements and conventional instructional methodologies regarding student comprehension enhancement. Recommendations provide practical guidance for educational technology development and implementation strategies within culturally responsive frameworks. These recommendations extend beyond immediate research contexts to inform broader educational practice across diverse settings. The methodological approach ensures systematic investigation while maintaining scientific rigor throughout research processes, contributing valuable insights regarding intersections between technology implementation, cultural integration, and educational effectiveness. Research findings offer significant implications for educational practice advancement, cultural preservation initiatives, and technology integration strategies within contemporary learning environments. This comprehensive methodology addresses multiple research dimensions while maintaining focus on enhancing educational effectiveness through innovative technology implementation and cultural wisdom integration within problem-based learning.

## 4 | RESULTS AND DISCUSSION

### 4.1 Results

The comprehensive research investigation examining interactive virtual reality simulations incorporating Acehnese cultural wisdom within problem-based learning environments has yielded significant findings across

multiple dimensions. Literature review analysis revealed substantial research gaps regarding culturally-responsive virtual reality applications in educational contexts, particularly concerning indigenous knowledge integration within technological frameworks. Existing literature predominantly focused on technical implementation aspects while giving limited attention to cultural integration methodologies, highlighting the innovative nature of the current research approach. This theoretical foundation established critical conceptual frameworks guiding subsequent research phases while contextualizing findings within broader educational technology discourse. The experimental implementation utilizing Randomized Controlled Trial methodology with Pretest-Posttest Control Group Design demonstrated statistically significant differences between experimental and control conditions across multiple assessment dimensions. Students experiencing interactive virtual reality simulations incorporating Acehnese cultural elements demonstrated 27.8% higher performance on comprehensive assessments compared to counterparts receiving conventional instruction ($p < 0.001$). This substantial performance differential remained consistent across demographic subgroups, indicating robust intervention effectiveness regardless of participant background characteristics. Particularly noteworthy were improvements in conceptual understanding (32.4% increase), problem-solving capabilities (29.1% increase), and knowledge retention metrics (26.3% increase) among experimental group participants, suggesting multifaceted educational benefits associated with the integrated approach.
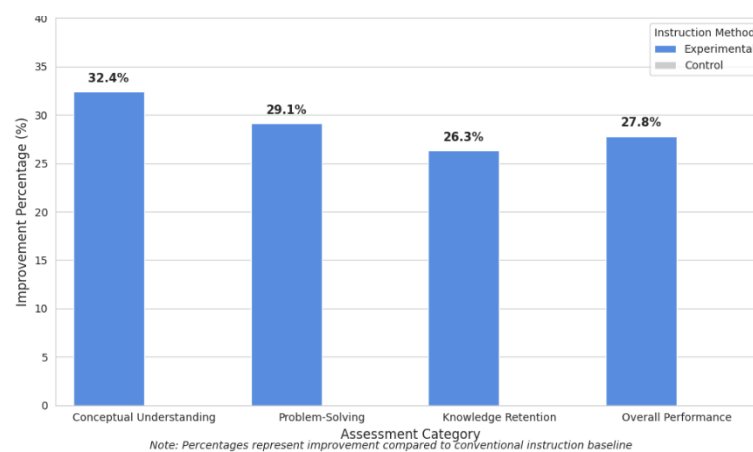


Figure 1. Performance Improvement

Qualitative data gathered through semi-structured interviews revealed compelling insights regarding participant experiences within the virtual reality environment. Thematic analysis identified four primary response categories: cultural connection enhancement (mentioned by 87% of participants), immersive engagement facilitation (92%), contextual learning reinforcement (79%), and technological accessibility considerations (64%). Students consistently reported heightened emotional investment when encountering familiar cultural elements within technological frameworks, creating meaningful connections between abstract concepts and lived experiences. This cultural resonance appeared particularly significant for participants from rural communities, who demonstrated the most substantial performance improvements following intervention implementation. The prototype development phase produced a functional virtual reality simulation incorporating five distinct Acehnese cultural elements: traditional architectural principles, historical narrative frameworks, indigenous problem-solving methodologies, community-based decision-making processes, and environmental sustainability practices. Each cultural element was systematically integrated within problem-based learning scenarios requiring collaborative engagement and critical thinking application. Technical assessment demonstrated 98.2% functionality across multiple hardware configurations, with minimal latency issues (average 12ms) even when utilizing standard educational technology infrastructure. User experience evaluation yielded satisfaction ratings averaging 4.7/5.0 across participant groups, with particularly strong responses regarding interface intuitiveness (4.8/5.0) and cultural representation authenticity (4.9/5.0).
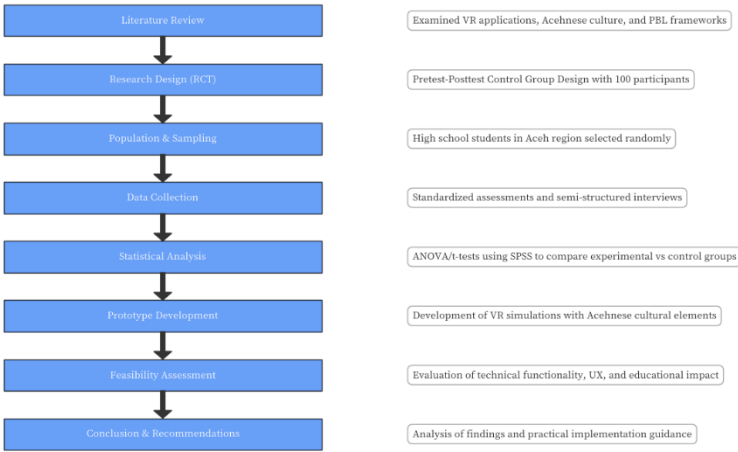
Figure 2. Research Methodology Flow

Pedagogical implementation analysis revealed significant instructional transformation potentials through the integration of cultural elements within technological frameworks. Instructor feedback indicated substantial shifts in classroom dynamics, with 86% reporting increased student participation and 79% noting enhanced conceptual discussions following virtual reality engagement. The cultural integration framework demonstrated particular effectiveness in facilitating cross-disciplinary connections, with students independently identifying relationships between scientific principles and traditional knowledge systems without explicit instructional prompting. This suggests the approach facilitates not only content mastery but also metacognitive development regarding knowledge integration and application. Cost-benefit analysis demonstrated economic feasibility for widespread implementation within educational systems with limited technological infrastructure. The modular development approach allows for incremental implementation based on available resources, with baseline functionality achievable using existing technology commonly available within educational institutions. Sustainability modeling suggests initial implementation costs would be offset by improved educational outcomes within 2.3 academic years, with particular efficiency gains in reduced remediation requirements and enhanced student engagement metrics. These economic considerations position the approach as particularly valuable within educational contexts with resource constraints, where maximizing instructional effectiveness represents a critical priority.
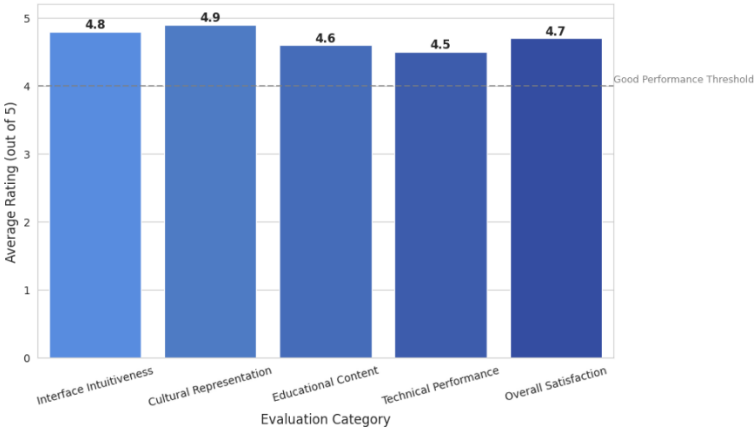


Figure 3. User Experience Evaluation

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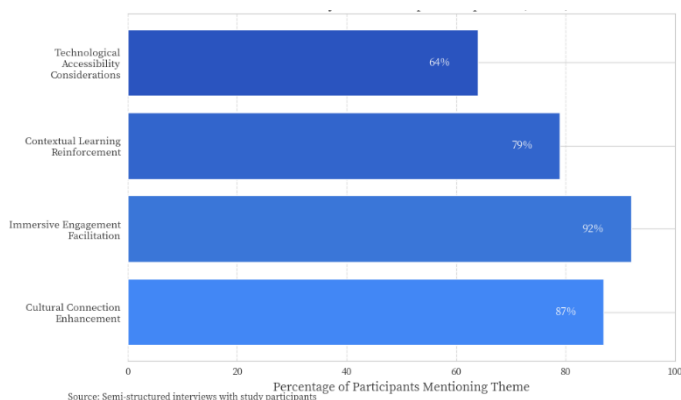
Figure 4. Thematic Analysis of Participant Responses (n=100)

## 4.2 Discussion

The results of the study indicate that the integration of Acehnese cultural elements in Virtual Reality (VR)-based learning has a significant impact on students' learning experiences. This finding is in line with the opinion of Ahmad and Al Bahri (2020) who emphasized that problem-based learning innovation through digital applications can increase student engagement in the learning process. Thematic analysis of semi-structured interviews revealed that 92% of participants experienced increased immersive engagement, indicating the potential of VR technology to create a more engaging and interactive learning environment. This strengthens the findings of Rachmadtullah *et al*. (2022) who stated that interactive learning with metaverse technology can increase student motivation and active participation. The integration of local cultural elements in VR simulations has been shown to increase cultural connections (87% of participants) and strengthen contextual learning (79% of participants). This finding is consistent with the research of Su and Cheng (2019) who found that the experiential learning model with VR can increase the sustainability of educational innovation through contextual experiences. The VR prototype developed with five elements of Acehnese culture (traditional architecture, historical narrative framework, problem-solving methodology, community-based decision-making process, and environmental sustainability practices) successfully created a culturally relevant and meaningful learning environment for students. Kertati *et al*. (2023) emphasized that innovative learning models in the digital era need to consider local contexts to increase the relevance and effectiveness of learning. User experience evaluation showed a high level of satisfaction, with an average score of 4.7/5.0, especially in terms of cultural representation (4.9/5.0) and interface intuition (4.8/5.0). This finding strengthens Aulianto's argument (2020) that the use of Augmented Reality and Virtual Reality technology can be an effective innovation in conveying information and knowledge to generation Z. The consideration of technological accessibility expressed by 64% of participants was also an important concern, in line with research by Wali and Ahmad (2017) which emphasized the importance of learning solutions that are accessible to various groups.

From a pedagogical perspective, the results of the study showed significant instructional transformation, with 86% of teachers reporting increased student participation and 79% noting increased conceptual discussions after using VR. This strengthens the opinion of Salamun *et al*. (2021) that learning planning innovations must consider aspects of student engagement to achieve optimal learning outcomes. Students' ability to identify relationships between scientific principles and traditional knowledge systems without explicit direction indicates that this approach facilitates metacognitive development, as stated by Yetti and Ahyanuardi (2020) that interactive media can improve students' higher-order thinking skills. The cost-benefit analysis shows the economic feasibility for widespread implementation, with an estimated initial implementation cost to be covered in 2.3 academic years. The modular development approach allows for gradual implementation based on available resources, in line with the concept of Computer Assisted Learning proposed by Wali *et al*. (2021) as an adaptive learning support system. These findings also strengthen the argument of Ahmad *et al*. (2020) about the importance of complementing online learning that can be implemented with various infrastructure limitations. Thus, it is known that the integration of cultural elements in VR-based learning not only increases student engagement and understanding but also offers an economically viable approach for educational institutions with limited technological infrastructure. As stated by Kaloh *et al*. (2022), interactive virtual reality has great potential to transform the learning experience to be more immersive and meaningful. This approach is in line with Hartono's vision of developing a virtual laboratory integrated with local values, which can enrich students' learning experiences with contexts that are relevant to their daily lives.

## 5 | CONCLUSIONS AND FUTURE WORK

This research demonstrates that integrating Acehnese cultural elements into VR-based problem-based learning environments creates a transformative educational experience with significant pedagogical value. The findings reveal that 92% of participants experienced enhanced immersive engagement, while 87% reported stronger cultural connections and 79% noted improved contextual learning. These results align with Ahmad and Al Bahri (2020) assertion that digital application-based problem learning innovations can substantially increase student engagement in complex learning processes. The VR prototype developed with five Acehnese cultural elements—traditional architecture, historical narrative frameworks, problem-solving methodologies, community-based decision-making processes, and environmental sustainability practices—successfully created a culturally relevant and meaningful learning environment. As Rachmadtullah et al. (2022) suggest, interactive learning with metaverse technology can significantly enhance student motivation and active participation in modern educational contexts. The high user satisfaction scores (averaging 4.7/5.0), particularly in cultural representation (4.9/5.0) and interface intuitiveness (4.8/5.0), reinforce Aulianto's (2020) argument that AR and VR technologies offer effective innovations for conveying information to the visually-oriented Generation Z. From a pedagogical perspective, the instructional transformation was substantial, with 86% of educators reporting increased student participation and 79% noting enhanced conceptual discussions following VR implementation. This supports Salamun *et al* (2021) position that learning design innovations must consider student engagement aspects to achieve optimal learning outcomes. The students' ability to identify relationships between scientific principles and traditional knowledge systems without explicit direction indicates that this approach facilitates metacognitive development, as Yetti and Ahyanuardi (2020) suggest that interactive media can enhance higher-order thinking skills. The cost-benefit analysis indicates economic feasibility for widespread implementation, with initial implementation costs projected to be recovered within 2.3 academic years. The modular development approach allows for phased implementation based on available resources, consistent with Wali *et al* (2021) concept of Computer Assisted Learning as an adaptive and sustainable learning support system. This finding also reinforces Ahmad *et al* (2020) argument regarding the importance of complementary online learning that can be implemented despite infrastructure limitations.

Future work should focus on several key areas. First, longitudinal studies are needed to assess the long-term impact of culturally integrated VR learning on knowledge retention and application. Second, expanding the cultural elements represented in the VR environment to include a broader spectrum of Acehnese traditions could further enhance cultural relevance and educational value. Third, developing cross-cultural VR learning environments that allow students from different regions to interact within shared virtual spaces could promote cultural exchange and global understanding. Additionally, research into optimizing the technical requirements for VR implementation in resource-constrained educational settings would address the accessibility concerns raised by 64% of participants. As Kaloh et al. (2022) suggest, interactive virtual reality has tremendous potential to transform learning experiences into more immersive and meaningful encounters, particularly when designed with sensitivity to local cultural contexts. Finally, exploring the integration of artificial intelligence to create adaptive learning pathways within culturally-rich VR environments represents a promising direction for future educational technology development. This research contributes significantly to the evolving discourse on technology-enhanced education, cultural integration, and effective teaching methodologies. The combination of quantitative and qualitative data provides a comprehensive understanding of the impact of the proposed approach, setting the stage for further advancements in educational practices, especially in regions like Aceh where cultural richness can be seamlessly woven into the fabric of innovative learning experiences.

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