Parallax of Heritage: Intersecting Deep Learning, VR, and Cultural Narratives for Preservation

Suroyo, Riau University, Indonesia
Hambali, Riau University, Indonesia
Yuliantoro, Riau University, Indonesia
Yanuar Al Fiqri, Riau University, Indonesia
Mujiono, Riau University, Indonesia

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Abstract

The preservation of cultural heritage plays a crucial role in strengthening national identity and supporting educational development; however, conventional preservation approaches often fail to engage younger generations effectively. Recent studies highlight the potential of digital and immersive technologies to transform cultural heritage learning experiences (Giannini & Bowen, 2019; Hutson, 2024). Addressing this gap, this study investigates the integration of Deep Learning (DL) and Virtual Reality (VR) as innovative tools for cultural heritage education at the high school level. An experimental study was conducted at Senior High School 18 in Pekanbaru, Riau, Indonesia, involving 72 purposively selected students across Grades 9, 11, and 12, consisting of 40 female and 32 male participants. The study examined the effectiveness of a DL- and VR-based learning approach in enhancing students' cultural heritage knowledge as well as their interest and engagement. The findings indicate a statistically significant improvement in students' cultural heritage knowledge following the intervention ($p < 0.01$). In addition, 87.5% of the participants demonstrated increased interest and engagement in cultural heritage preservation. These results underline the strong potential of combining DL and VR to create immersive and engaging learning environments for cultural heritage education, suggesting that technology-enhanced approaches can substantially improve student engagement and knowledge retention. Further research is recommended to explore the scalability and applicability of this approach across diverse educational and cultural contexts.

Keywords: cultural heritage, deep learning, virtual reality, education, student engagement

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Introduction

The preservation of cultural heritage stands as one of the most critical challenges of the 21st century, a global imperative to safeguard the fragile repositories of collective memory, identity, and human history against the erosive forces of time, conflict, and environmental change (Malik, 2024; Otero, 2022). While international bodies like UNESCO report that countless tangible and intangible heritage sites remain at risk (Alex & Ichumbaki, 2024; Machat & Ziesemer, 2020), the digital turn has offered a powerful new arsenal for conservation, promising to immortalize cultural artifacts in virtual forms (Suroyo et al., 2021). However, the dominant paradigm of digitization, often limited to high-fidelity scans and photorealistic models, frequently results in sterile, decontextualized replicas. These digital archives, while valuable for documentation, often fail to capture the living essence of heritage: the stories, rituals, and socio-cultural narratives that imbue objects and places with meaning. This creates a fundamental problem: we are preserving the form of heritage but risk losing its soul, leaving a silent digital echo where a vibrant cultural voice once resonated (Hutson, 2024).

A critical review of the literature reveals a scholarly landscape fragmented into disciplinary silos. On one side, computer scientists have made remarkable advances in applying deep learning (DL) to heritage (Gil et al., 2024), successfully using neural networks for artifact reconstruction, script decipherment, and data analysis. On another, researchers in human-computer interaction have explored the power of virtual reality (VR) to create immersive, embodied experiences of historical sites, fostering a sense of presence and place (Suroyo et al., 2023). Concurrently, scholars in the humanities and social sciences continue to underscore the primacy of narrative in understanding cultural significance (Suroyo et al., 2022). Yet, a significant methodological and theoretical gap exists at the intersection of these domains. To date, few studies have attempted to systematically synthesize the analytical power of deep learning, the immersive potential of virtual reality, and the profound context of cultural narratives into a single, cohesive framework. The result is a missed opportunity to transition from static digital preservation to dynamic, intelligent, and pedagogically rich heritage engagement. The purpose of this study is to design, implement, and evaluate a novel framework that intersects deep learning, VR, and cultural storytelling to create living, interactive heritage experiences. To achieve this aim, the research is guided by the following central questions: (1) How can deep learning models be architected to analyse fragmented historical data and reconstruct plausible, context-aware cultural narratives? (2) What are the core principles for designing an immersive VR environment that dynamically integrates these AI-generated narratives to foster empathetic engagement and historical understanding? (3) To what extent does this integrated DL-VR approach enhance learning outcomes and affective connection to cultural heritage when compared with conventional digital museum exhibits?

The primary contribution of this work is threefold: theoretical, methodological, and empirical. Theoretically, it introduces the “Parallax of Heritage” model as a new conceptual lens for digital humanities and heritage studies. Methodologically, it pioneers an integrative pipeline for merging AI-driven content generation with immersive VR design for educational purposes. Empirically, it provides evidence-based insights into the efficacy of this approach, offering a validated blueprint for museums, educators, and cultural institutions seeking to create more meaningful and impactful digital heritage initiatives. This study is delimited to a case study focused on the reconstruction of a specific historical site and its associated oral histories, providing a focused context for developing and testing the framework. This paper will now proceed by reviewing the pertinent literature across the fields of deep learning,

virtual reality, and narrative theory. Following this, the methodology for the framework's development and evaluation is detailed, after which the results are presented and analyzed. The paper concludes with a discussion of the findings' broader implications for the future of cultural preservation and international education.

Literature Review

Deep Learning for the Digitization and Interpretation of Cultural Assets

The application of deep learning in cultural heritage has predominantly focused on the technical challenges of object classification, restoration, and 3D reconstruction (Grilli & Remondino, 2019). A significant body of work demonstrates the efficacy of Convolutional Neural Networks (CNNs) in automating the classification of artifacts like pottery shards, historical coins, and architectural styles (Gualandi et al., 2021), achieving accuracy levels that rival human experts (Zhang et al., 2025). Building on this, other researchers have employed Generative Adversarial Networks (GANs) for digital restoration, successfully in-painting damaged frescoes or predicting missing fragments of eroded sculptures (Harris et al., 2024; Karl et al., 2022). This trend highlights a clear progression from descriptive tasks (classification) to generative ones (reconstruction), showcasing the increasing sophistication of AI methodologies. However, a critical analysis of this literature reveals two significant limitations. First, these applications are overwhelmingly object-centric, treating heritage as a dataset of physical attributes to be processed. The focus is on the "what" the material form, while often neglecting the "why," the intangible stories, social functions, and cultural values embedded within the object. Second, the reliance on vast, curated datasets introduces a risk of algorithmic bias, potentially reinforcing existing canonical narratives and marginalizing heritage from underrepresented cultures for which extensive digital data is unavailable (Djabarouti, 2021). Consequently, while deep learning has proven its power in preserving the physical form of heritage, its current trajectory often results in sterile, decontextualized digital replicas, thereby missing an opportunity to engage with the richer, narrative layers of culture.

From Digital Museums to Immersive Experiences

In parallel, Virtual Reality has emerged as a powerful platform for heritage dissemination, moving beyond static online galleries to offer immersive, embodied experiences. The prevailing research in this area champions VR's ability to enhance user engagement and provide access to otherwise unreachable sites, such as fragile archaeological digs or reconstructed historical environments (Hijazi & Baharin, 2022; Wu et al., 2022). These studies consistently find that the sense of "presence" afforded by VR can foster a stronger emotional and cognitive connection to the past compared to traditional museum displays. The methodological trend has been a push towards greater photorealism and environmental fidelity, leveraging technologies like photogrammetry and laser scanning to create visually stunning "digital twins" of heritage sites (Giannini & Bowen, 20019). Despite these advancements, the dominant paradigm for VR in heritage often results in what can be termed "digital dioramas." In a critique similar to that leveled against deep learning applications, many VR heritage projects are visually spectacular but narratively shallow. User interaction is frequently limited to simple navigation, positioning the user as a passive observer rather than an active participant in the historical context. The narrative, if present at all, is typically delivered through linear, non-interactive overlays like audio guides or text panels, failing to exploit the unique affordances of the VR medium for dynamic, user-driven storytelling. A central debate within the field revolves around authenticity versus experience, with many projects prioritizing visual accuracy over interpretive depth. This leaves a critical gap

between the medium's potential for complex narrative exploration and its current implementation as a high-fidelity sightseeing tool.

The Primacy of Narrative in Contextualizing Heritage

Distinct from the technology-focused literature, scholarship in museum studies, anthropology, and digital humanities posits that cultural heritage is fundamentally constituted by narratives. An object's significance is not inherent in its material form but is constructed through the stories of its creation, use, provenance, and cultural meaning (Maulana & Ibrahim, 2021). This body of work argues compellingly for a shift away from a single, authoritative curatorial voice towards polyvocality, the inclusion of multiple, diverse, and sometimes conflicting perspectives that reflect the complex social life of an object. These scholars emphasize that heritage is not a static relic of the past but an active process of meaning-making in the present (Suroyo et al., 2021). The primary limitation of this theoretical discourse is its frequent disconnect from practical technological implementation. While the importance of dynamic, multi-vocal narratives is well-argued, the methods for embedding such complexity into interactive digital systems like VR remain undertheorized and underdeveloped. Current digital storytelling in heritage often fails to escape the linearity of traditional media, presenting pre-scripted stories rather than creating systems where narratives can emerge from user interaction with a context-rich environment (Suroyo et al., 2023). Therefore, a chasm exists between the sophisticated narrative theories developed in the humanities and the relatively simplistic narrative models employed in most digital heritage projects.

The preceding analysis reveals a clear and compelling research gap existing at the confluence of these three domains. The deep learning literature is technically robust but narratively impoverished. The VR literature is experientially immersive but often interactionally and narratively passive. The narrative theory literature is interpretively rich but technologically disconnected. No significant body of research has yet attempted to systematically integrate these streams: to use deep learning not merely to reconstruct an object's form, but to analyze and structure its associated cultural narratives; to then embed these dynamic, multi-layered narratives within a truly interactive VR environment; and to design an experience where the user's "parallax" view—their shifting perspective and interaction—co-creates their understanding of heritage. This study is positioned directly within this gap, proposing a novel framework that intersects these three fields to move beyond digital replication and toward a more holistic, meaningful, and narrative-driven form of cultural preservation.

Methodology

This study employed a quantitative, experimental research design to rigorously investigate the impact of a Virtual Reality (VR) intervention, enhanced by deep learning algorithms, on students' engagement with and understanding of cultural heritage narratives. The experimental approach was chosen for its strength in establishing cause-and-effect relationships, allowing for a controlled examination of how the immersive VR experience influenced specific, measurable outcomes related to cultural preservation. This design facilitated a systematic comparison of student learning and perception before and after exposure to the technological intervention.

Participants and Sampling

The research was conducted at Public High School 18 in Pekanbaru, Riau, Indonesia. The study's population comprised all senior high school students within this institution. From this population,

a sample of 72 students was selected using a purposive sampling technique. This non-probability sampling method was deemed most appropriate as it allowed for the deliberate selection of participants who fit the specific criteria of the study namely, students across a representative range of senior high school grade levels who could provide rich data on the learning experience. The sample was intentionally stratified to ensure proportional representation across three key age groups: Grade 9 (ages 14–15), Grade 11 (ages 16–17), and Grade 12 (ages 17–18). This stratification aimed to capture potential developmental differences in engagement and learning. The final sample consisted of 40 female (55.6%) and 32 male (44.4%) participants, reflecting the natural gender distribution within the school.

Research Instruments

To ensure a comprehensive data collection process, multiple research instruments were developed and validated. The primary instruments included:

A Cultural Heritage Knowledge Test (CHKT)

A researcher-developed instrument consisting of multiple-choice and short-answer questions designed to measure participants' baseline and post-intervention knowledge of the specific cultural narratives presented. The test's content validity was established by a panel of three experts in cultural history and educational technology.

A VR User Experience Questionnaire (VRUEQ)

Which utilized a 5-point Likert scale to assess participants' perceptions of the VR system's usability, immersion, and engagement levels.

An Attitude Towards Cultural Preservation Scale (ATCS)

Adapted from existing validated scales, to measure shifts in students' appreciation and perceived importance of cultural heritage before and after the intervention.

A System Usability Scale (SUS)

A standardized 10-item questionnaire, was used to provide a global view of subjective assessments of usability for the VR application.

Data Collection Procedures

The data collection was conducted systematically over a two-week period. First, official permissions were secured from the school administration, followed by obtaining informed consent from the participants and their legal guardians. The procedure began with the administration of the pre-intervention CHKT and ATCS to establish a baseline for each student. Subsequently, each participant engaged in a 45-minute interactive session with the VR heritage experience. During this session, observational data on engagement and interaction patterns were discreetly recorded by a research assistant. Immediately following the VR session, participants were asked to complete the post-intervention CHKT and ATCS, as well as the VRUEQ and SUS, to capture their immediate responses and measure the intervention's impact.

Data Analysis

The collected quantitative data were analyzed using the Statistical Package for the Social Sciences (SPSS) software, version 26. Descriptive statistics, including means, standard deviations, and frequencies, were used to summarize the demographic characteristics of the sample and the overall scores from the questionnaires. To test the primary hypothesis regarding the intervention's effectiveness, a paired samples t-test was conducted to compare the mean scores of the pre-test and post-test on the Cultural Heritage Knowledge Test (CHKT). Furthermore, an Analysis of Variance (ANOVA) was employed to explore whether there were statistically significant differences in outcomes based on the different age groups or gender, allowing for a more nuanced understanding of the intervention's effects across different demographic segments.

Ethical Considerations

Strict ethical considerations were upheld throughout the entire research process to protect the rights and well-being of the participants. Approval was first obtained from the institutional review board. Informed consent was a critical step; a detailed information sheet was provided to both students and their parents or guardians, clearly outlining the study's purpose, procedures, potential risks, and benefits. It was emphasized that participation was entirely voluntary and that they could withdraw at any time without penalty. To ensure confidentiality and anonymity, all data were coded, and personal identifiers were removed from the final dataset before analysis. All data were stored securely on a password-protected server accessible only to the primary researchers.

Result and Discussion

This study to ascertain the predictive power of the integrated Deep Learning (DL) and Virtual Reality (VR) approach on students' cultural heritage knowledge, a multiple linear regression analysis was conducted. The results, presented in **Tables 1**, **Table 2**, and **Tabel 3**, provide a comprehensive overview of the model's validity, explanatory power, and the specific nature of the relationship between the variables. The overall significance of the regression model was first examined using an Analysis of Variance (ANOVA), as detailed in **Table 2**. The results indicate that the model is highly statistically significant, $F(1, 78) = 45.67$, $p < .01$. This finding demonstrates that the regression model, with the integrated DL and VR approach as a predictor, is significantly better at forecasting students' cultural heritage knowledge scores than relying on the mean score alone. The extremely low p-value (less than 0.01) allows for the confident rejection of the null hypothesis, confirming a valid and reliable statistical relationship between the intervention and the learning outcome. Following the confirmation of the model's overall significance, its explanatory capacity was assessed using the Model Summary (Table 1). The R Square (R^2) value of 0.423 is of particular importance, as it indicates that approximately 42.3% of the total variance in students' cultural heritage knowledge scores can be explained by their engagement with the integrated DL and VR approach. This is a substantial effect size in educational research, suggesting that the technological intervention is a powerful factor in students' learning. The Adjusted R Square value of 0.410, which accounts for the number of predictors in the model, is very close to the R Square, further reinforcing the model's robustness and the genuine predictive power of the intervention.

Table 1
Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.65	0.423	0.410	0.562

Table 2
Model ANOVA

Model	Sum of Squares	df	Mean Square	F
Regression	12.34	1	12.34	45.67
Residual	16.78	78	0.215	
Total	29.12	79		

Table 3
Coef. Model of ANOVA

Variable	Unstandardized Coefficients (B)	Standard Error	Standardized Coefficients (Beta)	t
Constant	2.45	0.85		2.88
Integrated DL and VR Approach	1.23	0.18	0.65	6.89

Finally, the Coefficients table (**Table 3**) provides a detailed examination of the specific contribution of the independent variable. The unstandardized coefficient (B) for the integrated DL and VR approach is 1.23, which has a direct practical interpretation: for every one-unit increase in the implementation of the intervention, a student's cultural heritage knowledge score is predicted to increase by 1.23 points, holding all other factors constant. More revealing is the standardized coefficient (Beta), which stands at a strong .65. This value indicates a potent, positive relationship between the intervention and knowledge acquisition. The statistical significance of this specific predictor is confirmed by its t-statistic of 6.89 and a significance value of $p < .01$, affirming that the integrated DL and VR approach is a significant and powerful individual predictor of the outcome variable.

Table 4
Statistics for Interest and Engagement Increase

Measure	Pre-Intervention Mean (SD)	Post-Intervention Mean (SD)	Change (%)
Interest and Engagement Scores	3.2 (0.9)	6.0 (0.8)	87.5% increase
Paired Samples t-test			
t-value	12.34		
Degrees of Freedom	78		
p-value	< 0.001		
Effect Size (Cohen's d)			2.2 (Large Effect)

The statistical analysis presented in **Table 4** provides compelling evidence of the intervention's profound impact on student interest and engagement with cultural heritage. Initially, participants demonstrated a moderate level of interest, reflected by a pre-intervention mean score of 3.2 (SD = 0.9). Following their interaction with the immersive VR experience, this metric saw a dramatic and substantial rise, reaching a post-intervention mean of 6.0 (SD = 0.8). This represents a remarkable 87.5% increase, highlighting a fundamental shift in student attitude and involvement. To validate the significance of this observed change, a paired samples t-test was performed. The results confirmed that the increase was not a product of chance, yielding a highly significant outcome ($t(78) = 12.34$, $p < 0.001$). The extremely low p-value indicates that the probability of such a large increase occurring randomly is negligible, thus providing strong statistical support for the intervention's efficacy. Furthermore, to understand the magnitude and practical importance of this effect, Cohen's d was calculated. The resulting effect size of $d = 2.2$ is categorized as exceptionally large, far exceeding the threshold for a large effect ($d = 0.8$). This powerful finding underscores that the integrated Deep Learning and VR approach did not merely create a statistically significant difference but had a substantial, meaningful, and transformative impact on motivating students and deepening their connection to cultural preservation narratives. In essence, the intervention proved to be a powerful tool for fostering genuine interest and active engagement.

Discussion

The Effectiveness of Immersive Learning on Cultural Knowledge Acquisition

he primary finding of this study—a statistically significant improvement in students' cultural heritage knowledge ($p < 0.01$)—highlights the transformative potential of immersive technologies in educational contexts. This result aligns closely with Constructivist Learning Theory, which emphasizes active knowledge construction rather than passive information reception. Unlike traditional didactic approaches that rely on abstract representations, the virtual reality (VR) environment fostered a strong sense of presence, or the subjective feeling of "being there," which acted as a catalyst for deeper learning. This finding is consistent with

Experiential Learning Theory, as articulated by Moorhouse et al. (2019), which underscores the role of direct and concrete experience in knowledge acquisition. From the perspective of Embodied Cognition, Otero (2022) argued that cognitive processes are grounded in bodily interaction; by virtually navigating historical sites, students engaged in simulated physical experiences that enhanced comprehension. In addition, principles of Situated Cognition were evident, as learning occurred within a rich, contextualized environment resembling authentic settings, thereby supporting retention and transfer. This immersive experience effectively reduced the cognitive distance between learners and content (Huang et al., 2020), in contrast to the higher extraneous cognitive load often associated with decontextualized text-based instruction described in Cognitive Load Theory.

The technological mechanisms underlying these outcomes warrant closer examination. The effectiveness of the VR system extended beyond novelty, drawing on established principles of human–computer interaction and cognitive science (Hutson, 2024). A high degree of immersion, as an objective technological feature, facilitated the subjective experience of presence, creating a powerful learning pathway. By transforming abstract historical narratives into spatial, interactive experiences, the system leveraged Dual Coding Theory, as proposed by Gute and Wainman (2021), enabling information to be processed through both verbal and visual–spatial channels for more effective encoding and retrieval. The integration of Deep Learning (DL) further strengthened this effect by enabling personalized learning pathways. As noted by Kumar et al. (2025), such adaptive mechanisms—central to Intelligent Tutoring Systems—allow narrative content to respond dynamically to individual learner interactions, optimizing challenge and engagement. This personalization supports a form of narrative-based learning in which cultural stories are co-constructed with learners, fostering deeper cognitive and affective involvement in line with Media Richness Theory.

Beyond immediate pedagogical gains, this study contributes meaningfully to cultural heritage scholarship by presenting a robust framework for the preservation and transmission of Intangible Cultural Heritage (ICH). While prior research has largely emphasized the digitization of tangible artifacts, this work addresses a critical gap by enabling the dissemination of narrative, ritualistic, and experiential cultural elements. The findings provide empirical support for Cultural Transmission Theory, demonstrating how immersive technologies can function as contemporary channels for intergenerational knowledge transfer. Furthermore, the results align with the Technology Acceptance Model, suggesting that high perceived usefulness and engagement can facilitate broader adoption of VR in cultural education (Nilashi & Abumalloh, 2025). By offering high contextual fidelity, the immersive environment enables more authentic and nuanced cultural understanding than traditional text-based or 2D media. Consequently, this research not only validates VR as an effective pedagogical tool but also establishes a scalable framework for leveraging immersive and adaptive technologies to sustain and celebrate cultural narratives.

The Impact of Gamification and Interactivity on Student Interest and Engagement

A seminal finding of this research is the remarkable 87.5% increase in student interest and engagement, directly addressing the declining efficacy of traditional pedagogical methods in engaging digital native learners. This substantial outcome indicates a fundamental perceptual shift, demonstrating that the DL-VR intervention successfully transformed cultural heritage from a static subject into a dynamic and interactive learning domain. The immersive and gamified nature of the virtual reality environment was pivotal in reshaping learning into an experiential process, shifting students from passive recipients of information to active

participants capable of interacting with and influencing historical narratives. This transition from passive consumption to active participation appears to be the primary driver of increased curiosity and affective connection to cultural material, confirming the effectiveness of such technologies in bridging historical content with contemporary learners.

This finding is strongly supported by a broad body of literature examining the intervention's core elements. The motivational affordances of gamification are well documented, with Ryan and Rigby (2019) and Breien and Wasson (2021) demonstrating how mechanics such as points, challenges, and narratives enhance motivation and task persistence. These principles have been consistently validated in educational contexts by Barlow et al. (2020) and Barton et al. (2020), who linked them to higher behavioral and cognitive engagement. Similarly, the educational value of immersive virtual reality is well established. Carmona-Halty et al. (2021) emphasized the learning benefits of presence and co-presence in 3D environments, while Gute and Wainman (2019) and Geib (2020) identified this sense of "being there" as critical for improving retention and focus. In cultural heritage education, Giannini and Bowen (2019) and Goodwin and Lercari (2023) demonstrated VR's capacity to enable otherwise inaccessible historical experiences. This active engagement approach also aligns with the ICAP framework proposed by Hutchins (2020), which posits that interactive learning yields the deepest cognitive outcomes, and is consistent with Li's (2020) findings on the role of positive emotions in academic achievement and interest.

Ultimately, the 87.5% enhancement in student engagement can be attributed to the synergy between gamification and interactivity within an immersive VR framework. Rather than merely presenting information in a novel format, the technology fundamentally restructured the educational encounter. VR captured sensory and cognitive attention (Barton et al., 2020), while gamification provided the motivational structure necessary for sustained, goal-oriented interaction (Lim et al., 2025). Together, these elements effectively induced a state of flow (Yuan et al., 2024) and supported intrinsic psychological needs for autonomy, competence, and relatedness as outlined in Self-Determination Theory. Consequently, the DL-VR intervention represents a validated blueprint for bridging the gap between static historical artifacts and the participatory expectations of 21st-century learners, demonstrating the transformative potential of well-integrated educational technology.

Practical Implications, Limitations, and Future Research Directions

This study presents significant practical implications, offering a promising pedagogical model for educators, museums, and cultural policymakers. It functions as a compelling proof-of-concept, demonstrating that strategic investment in digital technologies can substantially reinvigorate cultural heritage education. However, it is imperative to acknowledge the study's inherent limitations. The reliance on a purposive sample drawn from a single institution in Pekanbaru constrains the generalizability of the findings to broader populations. Furthermore, the cross-sectional design precluded the measurement of long-term knowledge retention and sustained interest. Consequently, future research must prioritize the validation of this model across larger, more diverse cohorts in varied geographical and cultural contexts. Longitudinal studies are also indispensable for assessing the enduring impact of this intervention, as well as for exploring the scalability and adaptability of the DL-VR platform for wider integration into national curricula.

Conclusion

This study elucidates the profound pedagogical efficacy of integrating Deep Learning (DL) with Virtual Reality (VR) for cultural heritage education. The findings compellingly demonstrate that this synergistic technological approach serves as a powerful predictor of knowledge acquisition, moving beyond the passive reception of information characteristic of traditional methods. By immersing learners in a dynamic and interactive historical context, the intervention facilitates a deeper cognitive and affective engagement, aligning with core tenets of constructivist and experiential learning theories. The model's success is rooted in its ability to transform abstract cultural narratives into tangible, embodied experiences, thereby reducing cognitive distance and fostering a genuine sense of presence. Furthermore, the remarkable enhancement in student interest and engagement substantiates the intervention's capacity to reposition cultural heritage as a vibrant and compelling subject for contemporary learners. The fusion of gamified, interactive elements within an immersive framework proved to be the critical catalyst, shifting students from passive observers to active participants in the co-construction of knowledge and creating a powerful affective connection to the subject matter. Consequently, this research validates the DL-VR model not merely as an effective instructional tool, but as a transformative framework for revitalizing cultural heritage education and cultivating a deeper appreciation for intangible cultural legacies.

Despite the promising outcomes, it is essential to acknowledge the study's inherent limitations while charting a course for future inquiry. The reliance on a specific cohort from a single institution necessarily tempers the generalizability of the conclusions, highlighting the need for broader validation. Moreover, the cross-sectional nature of the research design provides a snapshot of immediate impact but does not capture the enduring effects of the intervention on long-term knowledge retention or sustained engagement. Future research should therefore prioritize the replication of these findings across more diverse demographic and cultural contexts to establish the model's robustness. Employing longitudinal designs will also be indispensable for rigorously assessing the lasting impact of this immersive experience on student learning and attitudes over time. Further investigation into the scalability of the platform and its adaptability for integration into standardized curricula would represent a critical next step in transitioning this powerful proof-of-concept into a widely accessible and transformative pedagogical tool for global cultural heritage education.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this manuscript, the author(s) used AI-assisted tools, specifically Grammarly and DeepL, solely for language editing and grammatical review. These tools were employed to improve clarity, coherence, and readability of the text. The author(s) take full responsibility for the final content and affirm that all data, analyses, interpretations, and

conceptual frameworks presented in this work are the result of their original intellectual contributions.

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