

Designing Intuitive Environments: Creative Interaction, Educational Affordances, and Co-Design in Immersive Serious Games

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Abstract

Virtual Reality (VR) environments offer immersive experiences that deeply engage users with educational content. While trivia-based serious games successfully blend learning and entertainment, their implementation within VR remains underexplored. A critical gap exists in understanding how VR trivia games foster content knowledge, sustain motivation, and influence knowledge acquisition; empirical comparisons between VR and mobile formats are also lacking. This study addresses these gaps by presenting the design, development, and evaluation of Trivia World Quest, a VR serious game developed via a co-design approach. A comparative user study ($N = 43$) revealed that VR yielded significantly higher immersion, natural mapping, and visual engagement than its mobile counterpart. Additionally, a one-way ANCOVA, controlling for baseline knowledge discrepancies, demonstrated that the VR platform yielded significantly higher post-test knowledge retention than the mobile condition.

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1. Introduction

Although Virtual Reality (VR) and trivia-based serious games offer distinct pedagogical affordances for immersive education, their integration remains in its nascent stages. Prior work demonstrates that immersive VR experiences promote emotional engagement by enabling users to explore content through skill-adapted challenges, immediate performance feedback, and heightened presence [1]. Beyond replicating real-world scenarios, VR facilitates instruction within safe, engaging, and cost-effective environments. Crucially, the efficacy of the VR user experience is driven by both functional mechanics, such as challenge curves, progress feedback, defined goals, intuitive control, and audiovisual appeal [2], and psychosocial factors that modulate cognitive and emotional states, including

immersion, curiosity, autonomy, and a sense of mastery [3–5].

Parallely, digital serious games have well-documented success in fostering student motivation [6], deepening learning via immediate feedback loops [7], and stimulating cognitive development through experiential learning [8]. Within this landscape, trivia games centered on question-and-answer mechanics allow players to test existing knowledge, receive instant feedback, and learn iteratively through trial and error. By incorporating design strategies that stimulate intrinsic motivators (e.g., challenge, curiosity, and fantasy) alongside extrinsic mechanics (e.g., leaderboards and scoring systems), trivia-based frameworks reliably drive user engagement, cognitive reinforcement, and overall learner satisfaction [9, 10].

Despite these independent successes, the systematic implementation of trivia-based serious games within immersive VR environments remains substantially underexplored. This scarcity leaves a critical gap in

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the literature regarding how the unique affordances of VR, such as spatial presence, embodied interaction, and heightened sensory immersion, foster content knowledge acquisition and sustain intrinsic learner motivation over time. Crucially, existing research offers limited insight into how transposing text, or 2D, heavy quiz mechanics into a 3D spatial medium influences cognitive load and knowledge acquisition.

Furthermore, while mobile trivia games have demonstrated substantial potential for learner engagement [11, 12], empirical evaluations of their pedagogical utility within formal classroom environments remain sparse. This gap is particularly pronounced regarding the comparative efficacy of delivery modalities; there is currently little evidence to determine whether mobile or virtual reality interfaces are more effectively adaptable to school contexts to optimize student learning outcomes.

Trivia games are well documented drivers of learner satisfaction and cognitive reinforcement [9, 10], the functional utility and psychological implications of transposing these mechanics into a VR mediated environment, specifically when compared to established mobile formats, have yet to be rigorously examined. Furthermore, while both VR and trivia games possess the potential to generate positive educational outcomes, their combined efficacy as tools for integrated edutainment and assessment remains largely underexplored.

This paper contributes to the field by:

1. Detailing the design and development of a VR trivia game, employing a co-design approach to foster collaboration between industry and academia. We demonstrate how aligning pedagogical rigor with industrial imperatives, specifically regarding cost-efficiency and innovation, can optimize the design of immersive learning experiences, providing a foundation for future inquiry in the domain.
2. Building on existing research, we provide a comprehensive evaluation of the impact of psychosocial and functional factors on player experiences. We examine how these variables influence overall user satisfaction across two distinct trivia game modalities: virtual reality (VR) and mobile platforms.
3. Demonstrating how a shift in the technological medium influences student engagement and pedagogical efficacy. Our findings illustrate the relative impact of each delivery modality, offering evidence-based insights into the viability of VR trivia as an edutainment tool.

2. Literature Review

With the increasing accessibility of Virtual Reality (VR) systems, the development of immersive educational applications has emerged as a primary field of investigation. Among the teaching strategies adapted to this platform, trivia games stand out for their ability to integrate rapid assessment mechanics into a sensory-rich exploratory environment.

2.1. Virtual Reality

Virtual Reality (VR) technology fundamentally alters the educational landscape by enabling users to fully immerse themselves in computer-generated environments. At its core, VR relies on the state of immersion, which is the capacity of a system to render a vivid digital experience that absorbs the user emotionally, cognitively, and behaviorally, often to the extent of attenuating their awareness of the physical environment [13]. This is complemented by presence, defined as the psychological sensation of being physically located within the virtual space rather than one's actual surroundings [14].

These dual states move beyond simple digital interaction, meeting growing student demands for learning approaches that are active, engaging, insightful, and profoundly personalized [15]. By adapting to students' unique habits, preexisting knowledge, and competencies within the digital era, VR experiences offer a degree of instructional flexibility that traditional media cannot replicate [16]. Furthermore, this interactive nature enables the exploration of novel pedagogical methods, showcasing content from diverse perspectives that intrigue and appeal to users' curiosity both within and outside formal learning contexts.

The educational efficacy of these systems is grounded in established theoretical frameworks of human learning. For instance, by employing a constructivist approach, VR technology serves as a platform for active learning, where students do not merely ingest data but engage in contextualized tasks that allow them to synthesize and construct their own knowledge [17]. This is augmented by the experiential learning framework, which emphasizes the value of "in-context action" [18]. By creating virtual environments that mirror real-life interactions with people, objects, and places, VR makes abstract curricula more relatable to users' daily routines. In these digital environments, students can physically manipulate, scale, or reorient complex objects and systems, an action that creates concrete cognitive anchor points. Such interactivity allows learners to "learn by doing," reinforcing concepts through direct spatial engagement and significantly strengthening long-term retention and practical recall [19].

Beyond constructivist and experiential strategies, VR enhances the learning process by accommodating multimodal processing pathways, engaging visual, auditory, and kinesthetic sensory modalities simultaneously to optimize how individuals perceive and process information [20]. Visual processing benefits from the spatial rendering of abstract information, which allows learners to decode complex visuospatial structures and non-verbal cues. Conversely, auditory processing is supported by the capacity for integrated verbal instruction, localized narrative pitch, and acoustic emphasis within the virtual space. Finally, kinesthetic modalities—which are often under-stimulated in static, lecture-based environments—are uniquely activated by the hands-on, highly interactive nature of VR, allowing physical agency to drive conceptual understanding [20].

While existing research consistently highlights the benefits of gamification in immersive environments, a significant gap remains in the literature regarding the specific application of trivia-based mechanics. Despite the historical popularity of trivia as a mnemonic and formative assessment tool, there is a lack of rigorous investigation into how a VR trivia game can be effectively designed, optimized, and deployed as a targeted pedagogical tool within the classroom context. This indicates a critical need for further empirical research at the intersection of quiz-based game mechanics, immersive technology, and measurable learning outcomes.

2.2. Trivia Games and Gamified Assessment

While numerous variations of quiz-based digital games exist, their core structural mechanics remain fundamentally consistent: requiring players to evaluate and answer targeted prompts within defined temporal constraints or competitive scoring systems. In trivia games, gameplay typically involves retrieving information across a broad spectrum of conceptual domains, with a progressive difficulty-scaling matrix that dynamically challenges the user as they advance. Crucially, these systems leverage immediate feedback mechanisms, which serve the dual purpose of diagnosing a learner's prior knowledge and facilitating the active acquisition of new conceptual schemata through real-time error correction.

The assessment items in these environments are predominantly short-answer or multiple-choice questions. A primary pedagogical advantage of trivia games is their capacity to transform traditional rote assessment into an intrinsically motivating experience [21]. By structuring curriculum delivery in a competitive quiz format, learners are more likely to encode knowledge and achieve long-term retention through active cognitive engagement with the material [22]. This exposure to diverse thematic topics requires participants to

deploy varied cognitive strategies, thereby stimulating mental agility and processing faculties [23]. Furthermore, the integration of explicit gamification elements, such as points, badges, and immediate reward feedback loops for correct responses, significantly heightens user agency, reinforcing a compelling loop of sustained cognitive engagement and gameplay immersion [23].

Within formal educational and corporate training settings, gamified quiz applications have proven highly efficacious, providing educators with a dynamic, non-invasive methodology to reinforce core concepts and execute formative assessment [24]. These digital environments offer students a low-stakes framework to challenge their cognitive boundaries, evaluate their comprehension via immediate diagnostic feedback, and construct stable mental models through iterative trial and error. Simultaneously, the underlying game mechanics can foster prosocial classroom dynamics, stimulating healthy competitive or collaborative behaviours among peer groups.

In contemporary classrooms, this modality is frequently operationalized to evaluate student performance in real time via cloud-based Student Response Systems (SRS) such as Kahoot! [25]. These platforms offer instructional designers and educators high degrees of flexibility, allowing for rapid content customization aligned with specific curricular benchmarks. However, the literature also identifies distinct pedagogical limitations associated with these systems. For instance, researchers have noted that explicit countdown timers and public leaderboards can inadvertently induce academic anxiety, a fear of negative peer evaluation, or impulsive decision-making, in which students answer hastily to obtain higher scores in speed-based assessments rather than deeply reflecting on the underlying conceptual prompt [26].

3. Trivia World Quest: System Design and Development Methodology

The conceptualization, design, and development of the immersive application, *Trivia World Quest*, followed a highly structured, iterative lifecycle. The process commenced with the definition of the foundational game concepts, synthesized across multiple synchronous in-person (see Fig. 1) and asynchronous online collaborative design sessions. This co-design initiative was hosted and supported by the eGames Lab research centre in Funchal, an incubator specializing in fostering strategic industry-academia partnerships dedicated to the development and empirical evaluation of technological tools in education, sustainability, and socio-emotional well-being.

To achieve the application's primary objective of delivering an entertaining, low-anxiety, and deeply

immersive digital environment where users can evaluate and expand their knowledge across diverse conceptual domains, a cross-disciplinary design team was established. Each member provided iterative feedback informed by their respective domain expertise, balancing commercial viability with pedagogical rigour.

The *Design Team* benchmarked contemporary commercial VR titles, conducting a comparative analysis of two- and three-dimensional asset aesthetics, spatial user interfaces (UI), character ergonomics (encompassing both user avatars and companion agents), environmental assets (including dynamic lighting, color psychology, and ambient assets), and environmental narrative flow (see Fig. 2).

During the co-design phase, the enterprise's Chief Executive Officer (CEO) emphasized the necessity of modeling future commercial viability and market scalability to ensure long-term platform viability. While the primary academic focus rested on pedagogical integrity, the industrial leadership introduced considerations regarding future value-generation streams, such as scalable delivery frameworks and sustainable distribution architectures. To ensure the current study strictly isolated baseline learning outcomes and player experience mechanics, these commercial scaling pathways were explicitly excluded from the active software prototype. However, mapping these considerations during the co-design phase established critical strategic parameters for subsequent product commercialization and real-world market deployment phases.

The *Engineering and Programming Team* investigated specialized interaction design patterns in immersive spaces. They analyzed and integrated physical embodiment features, such as locomotion, localized object manipulation, and raycast/hand-tracking selection mechanics (e.g., precise grabbing, activating, and dropping triggers), alongside standard structural gamification loops (e.g., real-time scoring, point multipliers, and networked leaderboards). Crucially, priority was given to intuitive, natural mappings to maximize the user's perceived control when navigating in-game challenges. This deliberate interaction design aimed to mitigate excessive extraneous cognitive load, preventing working memory capacity from becoming overloaded by complex control schemas during task execution [27].

Operating within the agile, rapid-prototyping constraints of the industrial partner, the *Lead Academic Researcher*, specializing in serious games, educational technology, and immersive learning environments, structured the empirical research design to run parallel to system development. The researcher's responsibilities focused on identifying and validating design solutions that optimize user engagement through VR affordances, integrating evidence-based pedagogical strategies with gamification mechanics to construct a valid educational intervention.

Furthermore, recognizing that human-computer interaction (HCI) factors heavily dictate affective and cognitive states, the researcher established an integrative Co-Designed SDT-CLT Evaluation Framework. Grounded in Self-Determination Theory (SDT) [28], specifically the Player Experience of Need Satisfaction [29] and Cognitive Load Theory (CLT) [27], this framework operationalizes theoretical constructs into concrete spatial and interactive game elements developed during the co-design process. Specifically, it maps: (1) Extraneous Cognitive Load reduction to intuitive controls and spatial onboarding; (2) Affective stabilization and anxiety reduction to calm ambient exploration; and (3) Intrinsic need satisfaction (Autonomy and Competence) to progressive trivia loops and immediate multi-sensory feedback.



Figure 1. Team working session with programmer, CEO, researcher, and designer

3.1. Gameplay Mechanics and Environment Architecture

The VR trivia game was developed as a first-person experience leveraging the Unity game engine [30] and optimized for deployment on the Meta Quest 2 standalone Head-Mounted Display (HMD) [31]. The player progression is gated by the accurate retrieval of general knowledge information, benchmarking standard structural dynamics found in commercial digital quiz applications (e.g., Trivia Crack World [32]). However, to fully leverage the spatial affordances of VR, this core trivia loop is augmented by environmental riddles that require problem-solving skills and physical obstacles that necessitate direct, embodied interaction with the virtual surroundings.

To systematically evaluate the game's pedagogical and experiential objectives, the prototype architecture was partitioned into four distinct thematic zones (see Fig. 3), each serving a dedicated instructional and behavioral purpose:

- **Zone 1 (Tutorial and Onboarding - Cognitive Load Mitigation):** This initial phase is dedicated to user onboarding and mechanics acquisition. Players learn to calibrate the motion controllers,



Figure 2. Designer storyboard

navigate the 3D environment, execute spatial rotations, interact with physical assets (e.g., grabbing, manipulating, and dropping objects), and invoke the system's cognitive hint mechanics. Informed by CLT [27], this zone isolates interaction mechanics to eliminate control friction and minimize extraneous cognitive load, ensuring working memory capacity remains unburdened before educational content is introduced.

- Zone 2 (Baseline Exploration and Affective Stabilization):** This zone prioritizes environmental presence and open exploration. The spatial aesthetics are deliberately engineered to induce a relaxed, low-anxiety affective state, allowing users to become acclimatized to the digital space while answering baseline formative evaluation questions. Drawing on SDT's emphasis on low-anxiety environments for intrinsic engagement [28], the tranquil forest aesthetics stabilize user affect, placing players in an optimal emotional state for formative assessment.
- Zone 3 (Questions and Answers - Need of Satisfaction for Autonomy and Competence):** Designed to reinforce user agency and maintain intrinsic motivation, this area engages the player in a dedicated trivia loop. As users answer

questions correctly, they gather points, with each successful response triggering an immediate congratulatory animation and feedback loop to celebrate their achievement. Aligned with SDT and PENS [29], this zone satisfies the need for competence through immediate visual/auditory feedback upon correct answers, while supporting autonomy through continuous spatial movement choices along terrain category markers.

- Zone 4 (Completion and Extensible Portal):** Serves as the terminal phase, delivering a final congratulatory message. Designed as a spatial congratulatory transition into future levels, which were not implemented in the current study, it currently marks the formal end of the session.

Upon entering the game, the player is placed at the start of a path in a high-fidelity forest, where their progression is directly tied to answering questions. A trailhead information board acts as a natural in-game guide, showing which controls to use to navigate and interact with the world.

As the player explores the different forest scenarios, 3D symbols appear along the terrain to indicate a specific question category (see Fig. 4, a). Proximity triggers automate the process: as the player walks closer to a symbol, a floating menu displaying the question

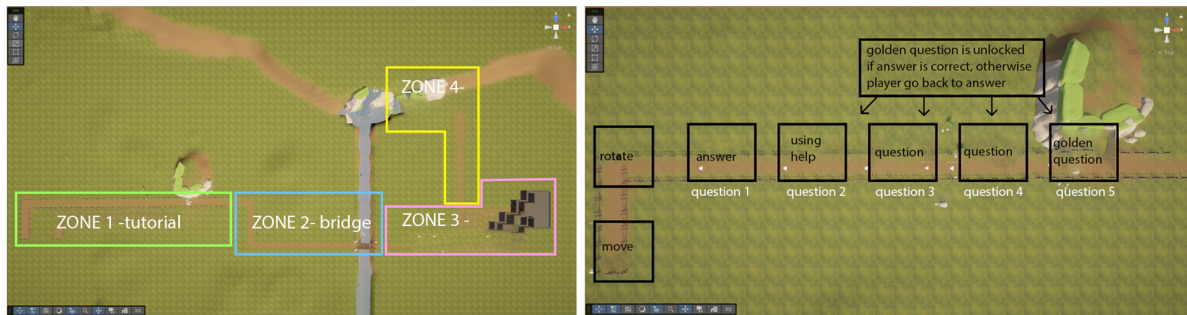


Figure 3. Overview of the game environment: (Left) layout of the four primary game zones; (Right) sub-divisions within Zone 1 tailored for player onboarding and mechanics acquisition



Figure 4. The player explores a 3D environment, finding icons that represent questions or tasks to complete and to earn points and unlock other sections of the forest

and multiple-choice answers pops up (see Fig. 4, b). By pointing and clicking to answer correctly, the player earns points and unlocks new areas of the forest to explore.

While the full scope of the game is designed to feature more extensive embodied interactions, a larger question bank, and additional mini-games and bonus rooms, this prototype was intentionally scaled down. This reduction was made to keep the experience closely aligned with the mobile platform version, ensuring a fair baseline for comparative user testing.

4. Methodology

We employed a mixed-methods research design to compare learning outcomes and emotional effects across two distinct platforms: an experimental group using the VR-based educational game and a control group accessing the same instructional content via a mobile application.

4.1. Participants and Sample Characteristics

The study initially recruited 47 students from two local public schools, who were assigned to one of two experimental conditions: the Virtual Reality (VR) experimental group ($n = 23$) and the mobile-based

control group ($n = 24$). Following the initial data collection, four participants were excluded from the analysis due to incomplete post-test data or non-response during follow-up inquiries. This attrition comprised three participants from the VR condition and one from the control condition. Consequently, the final analytical sample consisted of 43 participants (VR group: $n = 20$; control group: $n = 23$).

Demographic Profiles. Demographic characteristics varied slightly across the two conditions:

- **VR Experimental Group ($n = 20$):** Participants ranged in age from 13 to 15 years, with the vast majority (75.0%) being 14 years old. In terms of gender distribution, the sample was predominantly male (65.0%) with 35.0% female participants. Their interest in trivia games and prior familiarity with VR systems were exceptionally high, reported at 95.0% across the sample.
- **Mobile Control Group ($n = 23$):** Participants in this condition ranged in age from 14 to 16 years, with approximately half (47.8%) being 15 years old. This group exhibited a higher proportion of female participants (65.2%) compared to male

participants (34.8%). Additionally, a substantial majority (78.3%) of the group expressed a strong pre-existing interest in the trivia game genre.

The observed variation in gender distribution between groups was a byproduct of class-level assignment; potential implications of this imbalance are addressed in the limitations section.

4.2. Protocol, Instruments and Measurements

Since this study involved minimal-risk, routine educational and gamified testing activities for children (conducted in accordance with the Declaration of Helsinki and local regulations governing research with minors), formal Institutional Review Board (IRB) review was exempt. Recruitment commenced with a formal presentation by the lead researcher to school administrators and faculty, detailing the research protocol and assessment tasks involving the mobile and VR applications. Administrative and ethical approval for student participation was granted directly by the executive direction and administrative boards of the participating public schools prior to recruitment.

Once study logistics were finalized, written informed consent was obtained from the legal guardians of all minor participants prior to data collection. This consent explicitly addressed potential risks and granted authorization for the collection and use of research data, including photographic and video documentation. Additionally, verbal assent was obtained from all student participants, all data were fully anonymized to protect participant privacy, and participants were notified of their right to withdraw from the study at any stage without penalty. In addition to questionnaires, the study relied on interactions with the game's prototypes, interviews, and observation notes (see Fig. 5). Crucially, while both platforms featured identical trivia items and a closely mirrored user interface layout, the VR condition introduced an immersive 3D environment with unique visual and auditory aesthetics.

Data collection occurred across three overall school timetable sessions. The first two sessions comprised the VR experimental condition ($n = 11$ and $n = 12$, respectively), while the third session served as the mobile control condition ($n = 24$). To accommodate the hardware constraint of four active HMDs, participants in each VR session were organized into sequential rotation waves of up to four students at a time. While these participants actively engaged in the VR environment, remaining students completed a classwork assignment.

The evaluation followed a four-stage sequential protocol across all testing sessions:

1. **Pre-Test and Baseline Assessment:** Participants first completed a digital survey assessing demographic background and general interest in trivia games. To screen for potential comfort issues, participants assigned to the VR condition were additionally evaluated for motion sickness susceptibility and prior VR experience. All participants then completed a 20-item baseline general knowledge quiz aligned with their school curriculum (Appendix A). To note that all 20 baseline and post-test quiz items, as per Bloom's taxonomy, exclusively evaluated lower-order cognitive domains, such as remembering (factual and terminology knowledge; e.g., Q3: capital of Malawi, Q5: unit of electrical resistance) and understanding (conceptual knowledge; e.g., Q8: definition of Arkose rock).
2. **Gameplay and Observation:** Next, participants played their assigned version of the game, starting with a quick tutorial to learn the controls (see Fig. 6). While the control group used a mobile screen, the experimental group navigated the 3D VR forest. During gameplay, two researchers took notes on the participants' real-time reactions, physical movements, and comments. For the VR sessions, the researchers used an iPad to mirror exactly what the players were seeing and doing inside the Meta Quest 2 headsets.
3. **Post-Game Survey:** Immediately after playing, participants filled out an experience scale adapted from Self-Determination Theory (SDT) [28] and the Player Experience of Need Satisfaction (PENS) framework [29]. This survey looked at the game experience on two levels: *Functional Consequences* (how direct design choices like the graphics or controls felt) and *Psychosocial Consequences* (deeper feelings like immersion, competence, and autonomy). To see how natural the controls felt, we also added a few items from Skalski's natural mapping scale [33]. All questions were scored using a standard 7-point Likert scale (1 = "strongly disagree" to 7 = "strongly agree").
4. **Exit Interview:** Finally, participants completed a brief semi-structured interview to share their thoughts on usability, enjoyment, and overall value. The questions included:

"What did you enjoy the most? If you could change the game, how would you do it? Would you recommend the game to a family member or friend? How long do you think you were playing? Would you be willing to pay for this game? How was the overall experience?"

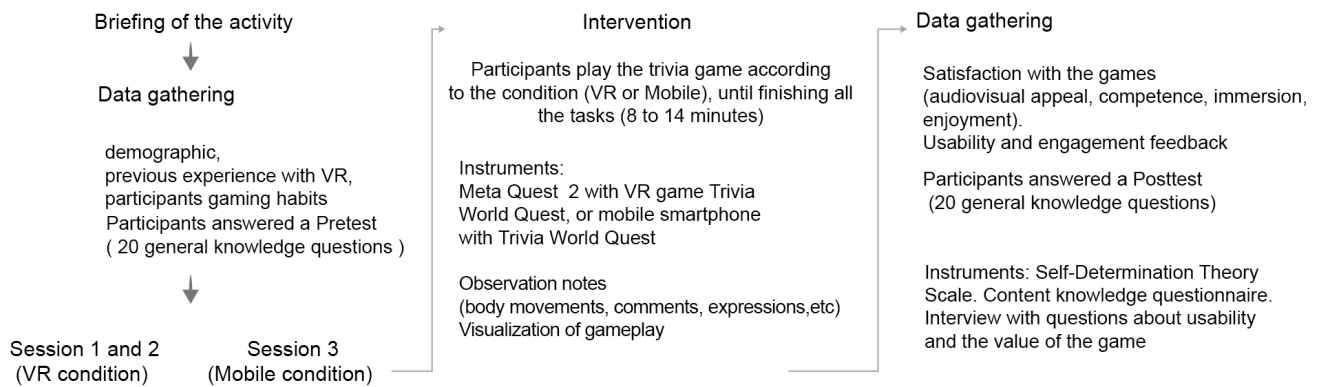


Figure 5. Study design diagram



Figure 6. Study Interactions

Quantitative data were compiled and analyzed using SPSS (Version 25.0; IBM Corp., Armonk, NY, USA). We ran two-tailed significance tests, setting the standard threshold for statistical significance at $\alpha = 0.05$.

5. Results

The internal consistency of the measurement scales was evaluated using Cronbach's alpha (α). The dimensions tracking participant satisfaction demonstrated high reliability, with coefficient values ranging between $\alpha = 0.79$ and $\alpha = 0.88$. Similarly, the knowledge assessment questionnaires exhibited strong internal consistency, showcasing an $\alpha = 0.78$ for the pre-test and $\alpha = 0.80$ for the post-test. Together, these values indicate robust reliability across all measurement instruments used in the study.

5.1. Knowledge Acquisition Results

To examine differences in knowledge acquisition between the platforms while accounting for baseline discrepancies, a one-way Analysis of Covariance (ANCOVA) was conducted. The independent variable was the gaming platform (VR vs. Mobile), the dependent variable was the post-test knowledge score, and the pre-test knowledge score was included as a covariate. Preliminary data screening checked the critical

assumption of homogeneity of regression slopes. The interaction between the platform group and the pre-test score was not statistically significant, $F(1, 39) = 1.34, p = .254$, indicating that the relationship between pre- and post-test performance was consistent across both conditions, validating the use of ANCOVA. The main ANCOVA, revealed a highly significant effect for the pre-test covariate, $F(1, 40) = 40.51, p < .001$, partial $\eta^2 = .503$, accounting for 50.3% of the variance in the outcome scores. Crucially, after statistically controlling for these initial baseline knowledge variations, a highly significant main effect was found for the gaming platform, $F(1, 40) = 31.87, p < .001$, partial $\eta^2 = .443$. This represents a large effect size, indicating that the medium itself explained 44.3% of the remaining variance in knowledge retention. The estimated marginal means revealed that when baseline scores were mathematically equalized ($M = 8.09$), participants in the VR condition achieved significantly higher adjusted post-test scores ($M_{adj} = 16.63, SE = 0.35$) than those in the Mobile condition ($M_{adj} = 12.39, SE = 0.33$) (see Figure 7).

Due to demographic imbalances between the groups, specifically a higher proportion of 14-year-old males in the VR condition (65.0%) and a higher proportion of 15-year-old females in the mobile condition (65.2%) a secondary, comprehensive ANCOVA was conducted

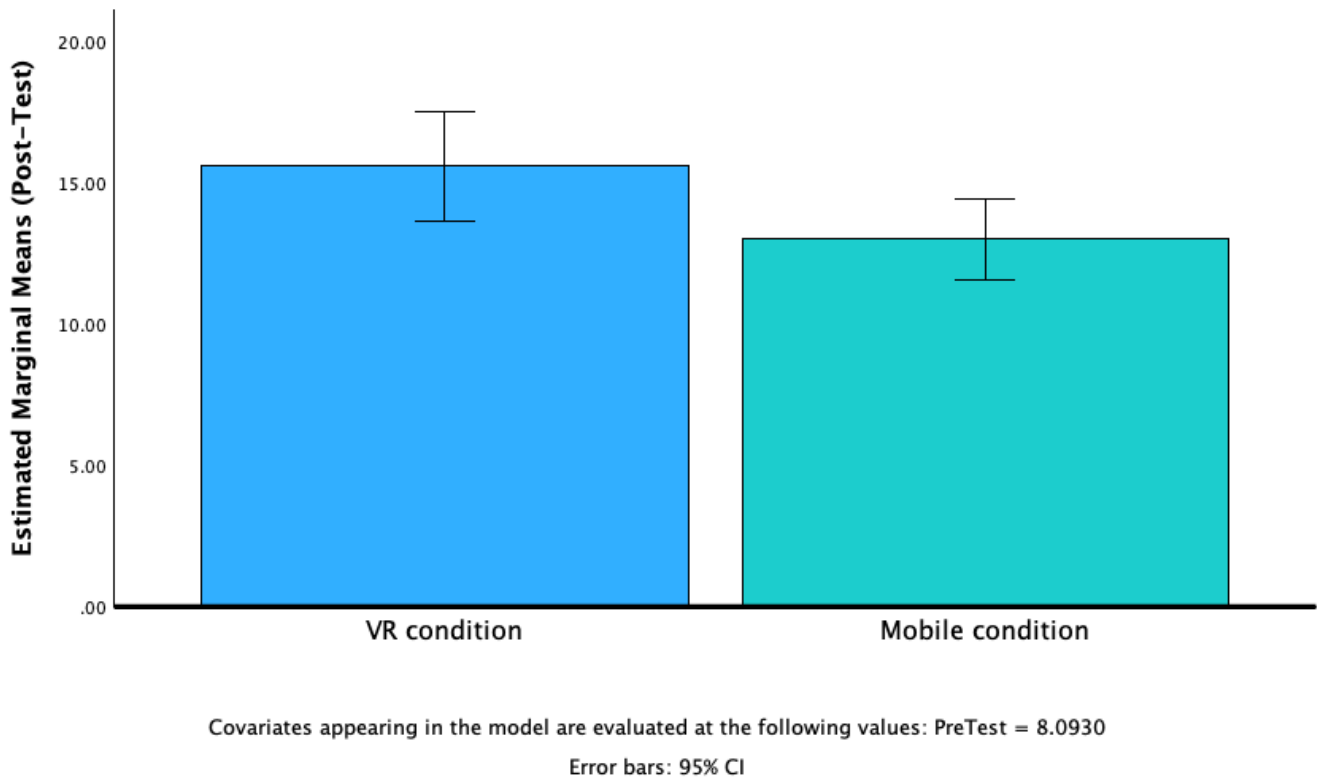


Figure 7. Pre-test and Post-test content knowledge score trajectories

to verify that these discrepancies did not confound the main findings (see in Table 2). The analysis revealed that neither gender, $F(1, 38) = 0.05, p = .821, \eta_p^2 = .001$, nor age, $F(1, 38) = 0.01, p = .941, \eta_p^2 < .001$, demonstrated a statistically significant influence on post-test knowledge retention. Crucially, even when forcing the model to simultaneously account for these demographic variables alongside the baseline covariate, the main effect of the platform condition remained highly significant, $F(1, 38) = 10.37, p = .003, \eta_p^2 = .215$, confirming that the primary results reported in Table 1 are highly robust against demographic skew.

5.2. Players' Satisfaction

The psychological impact of the intervention was analyzed using non-parametric methods (Mann-Whitney U) due to violations of normality in the Immersion and Competence dimensions. Participants in the VR condition reported significantly higher levels of immersion than those in the mobile condition ($U = 85.50, z = -3.56, p < .001, r = .54$). Conversely, no statistically significant difference was observed between the groups for the Competence dimension ($U = 190.50, z = -0.97, p = .330, r = .15$).

Parametric assumptions were met for Audiovisual appeal, Enjoyment, Value, and Natural Mapping, as assessed by the Shapiro-Wilk test ($p > .05$).

Independent samples t-tests revealed that participants in the VR condition reported significantly higher scores for Audiovisual appeal ($M = 16.65, SD = 2.35$ vs. $M = 13.74, SD = 2.43$), $t(41) = 3.98, p < .001, d = 1.22$, and Natural Mapping ($M = 34.95, SD = 2.98$ vs. $M = 30.43, SD = 2.25$), $t(41) = 5.65, p < .001, d = 1.73$. Additionally, Enjoyment was significantly higher in the VR condition ($M = 33.90, SD = 4.32$ vs. $M = 31.48, SD = 3.33$), $t(41) = 2.08, p = .044, d = 0.63$ (see Figure 8). For all significant findings, effect sizes were substantial, exceeding the threshold for a large effect [34].

Regarding prior technology exposure, five participants in the VR condition noted a history of motion sickness during past, unrelated virtual reality experiences. However, during and after gameplay, none reported feeling dizzy, nauseous, wanting to vomit, or any other symptoms associated with motion sickness. The participants in both condition reported completing all the tasks and finishing the game.

Participants in both conditions consistently underestimated their elapsed playtime. In the VR condition, where the gameplay lasted approximately 15 minutes, the average perceived duration was just 6 minutes. A similar trend was observed in the mobile condition, with participants estimating an average of 4 minutes for an actual 8-minute session.

Table 1. Univariate Analysis of Covariance (ANCOVA) for Post-Test Knowledge Acquisition

Source	Type III Sum of Squares	df	Mean Square	F	p	Partial η^2
Corrected Model	328.750 ^a	2	164.375	35.337	< .001	.639
Intercept	501.990	1	501.990	107.922	< .001	.730
Pre_Test (Covariate)	188.406	1	188.406	40.505	< .001	.503
Group (Platform)	148.219	1	148.219	31.865	< .001	.443
Error	186.062	40	4.652			
Total	9598.000	43				
Corrected Total	514.814	42				

^a R Squared = .639 (Adjusted R Squared = .621)

Table 2. Secondary ANCOVA Robustness Check Controlling for Demographic Imbalances. It confirms statistical stability of the primary intervention effect

Source	SS	df	MS	F	p	η_p^2
Pre-test (Covariate)	—	1	—	15.65	< .001	.292
Gender	—	1	—	0.05	.821	.001
Age	—	1	—	0.01	.941	< .001
Platform Condition	—	1	—	10.37	.003	.215
Error	—	38	—			

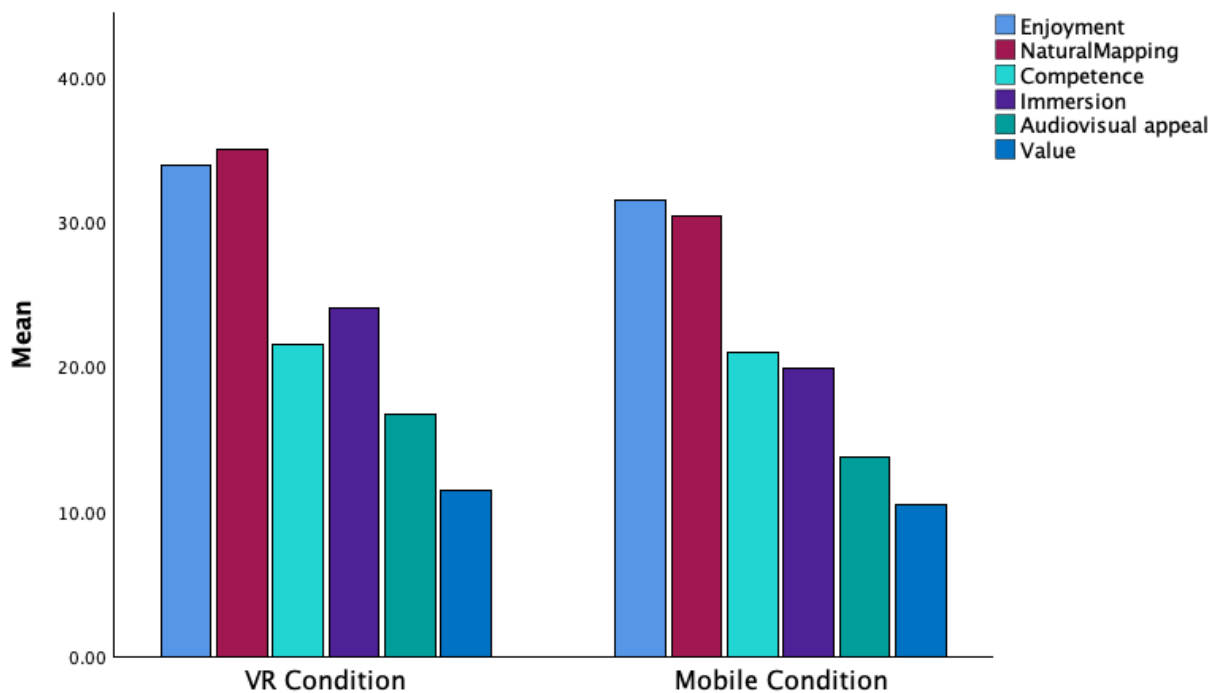


Figure 8. Players Satisfaction Dimensions Comparative Analysis for VR and Mobile Conditions

5.3. Qualitative Data and Observational Findings

The quantitative metrics were further supported by qualitative data and structured observation logs, which

showed that participants in both conditions thoroughly enjoyed the core game mechanics.

Table 3. Comparison of Player Experience Dimensions Between VR and Mobile Conditions

Dimension	VR (N = 20)		Mobile (N = 23)		Statistic (p, Effect Size)
	Mean / Rank	SD	Mean / Rank	SD	
Parametric (t-test metrics) / reported as M, SD					
Audiovisual appeal	M = 16.65	SD = 2.35	M = 13.74	SD = 2.43	t(41) = 3.98, p < .001, d = 1.22
Enjoyment	M = 33.90	SD = 4.32	M = 31.48	SD = 3.33	t(41) = 2.08, p = .044, d = 0.63
Value	M = 11.40	SD = 1.79	M = 10.48	SD = 1.31	t(41) = 1.95, p = .059, d = 0.60
Natural Mapping	M = 34.95	SD = 2.98	M = 30.43	SD = 2.25	t(41) = 5.65, p < .001, d = 1.73
Non-Parametric (Mann-Whitney U metrics) / reported as Mean Rank					
Competence/mastery	Mean Rank = 23.98		Mean Rank = 20.28		U = 190.50, p = .330, r = 0.15
Immersion	Mean Rank = 29.23		Mean Rank = 15.72		U = 85.50, p < .001, r = 0.54

User Engagement and Perceived Value. In the VR condition, participants highlighted several distinct factors that drove their engagement, focusing primarily on environmental navigation and reward systems. Feedback included remarks such as: “Walking around and answering questions about multiple topics was fun,” “The movement felt fluent,” and “I liked the fact that there were different types of questions, and rewards”

Participants in the mobile condition mirrored this high level of satisfaction, with one user noting: “I have played a similar game before, but this one has different questions and I really like it.” Notably, every participant across both conditions indicated a willingness to purchase the game.

The educational utility of the application also received strong validation. A majority of participants in both the VR ($n = 18$) and mobile ($n = 18$) groups characterized the system as an “excellent tool to learn about different areas” or “a great tool for learning.”

Aesthetics, Atmosphere, and Audio. Reflecting on the visual design, participants expressed strong acceptance of the application’s atmosphere, though reactions were more enthusiastic within the immersive condition:

- **VR Condition ($n = 20$):** Participants highly praised the spatial environment, noting: “I enjoyed seeing the changing scenarios by walking around,” “I liked the calm nature of the ambient,” and “I enjoyed the UI, the design of the world, and the symbols.” The companion non-player character (NPC), a small bird accompanying the player, was frequently highlighted as “cute.” Additionally, twelve participants explicitly cited the spatial sound effects as a standout positive feature.
- **Mobile Condition ($n = 8$):** Feedback regarding the 2D visuals was positive but more tempered. Participants noted that “the game was colorful,” “the icons represented the areas well,” and that the interface maintained a “clean and appealing look.”

Participant Recommendations and Future Refinements.

While the initial reception was highly promising, participants identified specific vectors for future refinement. The most frequent critique focused on question repetition and a desire for a broader question pool. This behavior was expected, as this specific testing prototype was restricted to a controlled baseline of 20 questions rather than the full planned data set. Students also requested the implementation of a dynamic difficulty system, such as a “hard mode” featuring a 30-second response limit, alongside the ability to manually select specific trivia categories.

Furthermore, participants in the VR group expressed a strong desire for expanded interactivity and agency within the virtual space, stating:

“I would enjoy having more freedom to look around the forest, with more paths,”
 “I want the possibility to walk faster,”
 “Show hands in the game instead of the controllers,” and
 “Always show the correct answer, even if I got it wrong.”

Observational Field Notes. Direct researcher observations successfully complemented these self-reported entries. Players in both conditions routinely exhibited positive affect, such as smiling, while navigating the environments and registering correct answers. High levels of focus were apparent across both groups; participants frequently moved their lips silently while reading the trivia questions. Conversely, minor frustration was observed in four participants following an incorrect response, typically manifested by dropping or lowering their arms.

A stark behavioral divergence was noted regarding social dynamics: participants in the mobile condition engaged in significantly more peer-to-peer interaction. These students frequently vocalized their progress to the room (e.g., “I just got question 4 right!”), and looked around the space to monitor their peers’ screens, and

actively compared final scores upon completing the session.

6. Discussion

This paper presents the design, development, and evaluation of a Virtual Reality (VR) trivia game compared against a traditional mobile format. Although the primary objective of this research was not to formally evaluate the co-design process itself, the collaborative framework involving both academic and industry stakeholders yielded critical insights that we believe are highly valuable for the field. Engaging multiple sectors early in the development lifecycle facilitated the rapid identification of strategic mechanics, allowing the team to successfully balance rigorous educational goals with innovative user experience (UX) design solutions.

Methodological and Collaborative Insights

A significant challenge in this cross-sector collaboration was reconciling the disparate timelines inherent to industry product development and academic research. When validating educational games through formal protocols, particularly with younger populations, researchers cannot afford to wait until after institutional authorization is fully secured to begin study design. Instead, a proactive, bottom-up strategy is required. In school settings, teachers serve as vital partners in identifying optimal windows for study deployment according to the curricular requirements, pedagogical practices, and logistical constraints of the classroom. If this bottom-up approach is ignored, the academic research process can become bottlenecked, stalling the rapid iteration cycles essential to the industry development lifecycle.

Furthermore, establishing a foundation of trust with industry partners remains imperative. The presence of external academic researchers in proprietary product development meetings can easily be perceived as an operational or intellectual property risk. Sustained dialogue is therefore necessary to align the distinct priorities of both parties. For the industry partner, this collaboration provides actionable, empirical insights into whether their technology, visuals, and control schemes are optimized for the target demographic prior to market release. When obtained early in the development cycle, such data facilitate high-fidelity iterative improvements, directly enhancing the product's market viability and commercial potential. Simultaneously, academic researchers leverage the developed artifact to evaluate user experience and technological performance, thereby optimizing research efforts and university resource allocation. Ultimately, a successful intersectoral study must be meticulously designed to reconcile these concurrent objectives, clearly demonstrating how the technological innovation adds measurable value over established industry paradigms.

Reflecting on the co-design framework as a whole showcased critical operational takeaways regarding what succeeded, what requires future refinement, and how these practices extend to broader domain contexts.

Early interdisciplinary co-design meetings allowed for the integration of core educational theories, specifically Cognitive Load Theory and Self-Determination Theory, directly into interaction mechanics. Embedding these theoretical principles during initial architecture, rather than retrofitting them post-development, allowed the team to execute rapid iterative prototyping without compromising visual quality or empirical rigor.

Retrospectively, the co-design methodology could be optimized in one key area. First, while students and educators participated in intervention testing, involving them as active co-designers during initial ideation workshops, would provide richer insights into student interaction preferences and classroom usability early in development.

Ultimately, these methodological takeaways extend well beyond the immediate scope of VR trivia games, offering a generalizable framework for interdisciplinary initiatives across Human-Computer Interaction (HCI), Educational Technology, Serious Game Design, and Instructional Science. By demonstrating how to reconcile rapid industrial iteration with empirical rigor, establish operational trust, and create dual-purpose artifacts, this work provides a scalable operational blueprint for managing cross-sector industry-academia partnerships across emerging digital media domains.

Immersive Trajectories and Theoretical Underpinnings

In this study, we evaluated content knowledge acquisition to understand the educational advantages of the immersive VR medium compared to a mobile format. By using a one-way ANCOVA with pre-test scores as a continuous covariate, we controlled for initial differences in baseline knowledge between the two groups.

The analysis revealed a statistically significant main effect for the experimental condition, using the VR trivia game. This means that when baseline knowledge variations are factored out, the VR condition leads to significantly higher post-test knowledge retention than the mobile condition. This finding is important because it demonstrates that the learning benefits driven by the VR intervention do not depend on how much a student knew before starting the game. Rather than only helping students who already had prior knowledge, the VR format uniformly improved learning outcomes across the entire group.

This performance advantage is directly supported by the player experience metrics. Participants in the VR condition reported significantly higher levels of immersion, visual engagement, and natural mapping than those in the mobile condition.

These positive results may be attributed to the player's sense of agency and physical embodiment, frequently conceptualized as the "hands-in" experience, wherein embodied interactions involving spatial physical movement enhance psychological presence in digital environments [35]. High levels of natural mapping were observed within the virtual reality environment, where participants successfully navigated, completed all assigned tasks, answered questions, and comprehended overall mechanics. In this sense, Zone 1 effectively eliminated control friction, as evidenced by zero participant dropouts during onboarding. Furthermore, mechanics that emulate natural motion mapping positively influence the satisfaction of basic psychological needs for autonomy and competence. In Zone 3, the continued implementation of immediate rewards, animations, and congratulatory feedback was well received and significantly increased participant motivation to continue, establishing this dedicated trivia loop as a key pillar of the overall VR experience.

We also believe that the novelty effect was overcome, by the previous access to the VR technology, expressed by the group prior to the study, while we do not discourage that the intuitive interactions diminish extraneous cognitive load. By aligning interactive elements with intuitive, real-world ergonomics, the system reduces unnecessary cognitive barriers, enabling users to preserve working memory and maintain focus on the educational content.

This preservation of working memory and the resulting positive results in post-test retention, can be understood through Sweller's Cognitive Load Theory [36]. In immersive 3D environments, rich sensory inputs and spatial navigation risk introducing extraneous cognitive load that competes with the germane load required for content learning. However, by eliminating interface friction through intuitive and natural motion mapping, the VR system successfully minimized this environmental processing burden. This cognitive economy allowed participants to direct their unburdened working memory toward germane processing, enabling the heightened immersion and spatial engagement of the VR format to translate directly into higher knowledge retention over the mobile condition. Consequently, when interaction design successfully mitigates extraneous load, sensory fidelity scaffolds rather than distracts from core educational objectives.

Beyond balancing cognitive economy, the pedagogical scope of trivia-based game mechanics must be contextualized within Bloom's taxonomy. While our findings demonstrate efficacy for lower-order cognitive domains, namely factual retention and conceptual recall, trivia formats are inherently limited in cultivating higher-order cognitive objectives such as synthesis, critical evaluation, or abstract problem-solving. Future

research should investigate how immersive VR mechanics can transcend foundational recall to scaffold these higher-order cognitive processes in complex domain learning.

Environmental Psychology and Interface Design

The qualitative results strongly corroborate the quantitative indicators, with VR participants reporting high satisfaction regarding visual fidelity, spatial navigation, and overall audiovisual appeal. Although the absence of a baseline pre-test prevents definitive measurement of anxiety reduction, our findings demonstrate that Zone 2 was highly effective in stabilizing user affect. Specifically, the ambient audio landscape and natural forest environment cultivated a tranquil atmosphere that deeply anchored participants within the experience. Supported by prior research [1], this immersive setting put players at ease, enhancing their sense of presence and driving spontaneous engagement with the game's activities.

Although a comprehensive evaluation of environmental psychology falls outside the immediate scope of this paper, our data suggest that this environmental design optimizes a player's capacity to focus and reflect on pedagogical prompts compared to traditional mobile alternatives [37]. Specifically, the low-stress VR atmosphere mitigates the temporal urgency and performance anxiety commonly induced by competitive, rapid-fire mobile trivia settings [26].

Additionally, the integration of a virtual companion avatar emerged as a notable factor in user comfort. Its benefits may stem from real-time positive visual feedback, a perceived sense of companionship that reduces HMD-induced isolation, or its utility as a navigational guide, hypotheses that warrant dedicated empirical investigation in future studies.

Platform Trade-offs and System Refinements

While the VR environment fostered deep individual focus, observational data revealed an important trade-off regarding social dynamics.

Participants in the mobile condition engaged in significantly more frequent social interactions, such as sharing immediate reactions and comparing progress peer-to-peer. This divergence highlights a key trade-off for integrating Head-Mounted Displays (HMDs) into real-world educational settings. The physical and sensory occlusion of the VR headset effectively eliminates environmental distractions, promoting deep personal absorption and a relaxing, highly focused atmosphere that minimizes performance anxiety. However, this same sensory isolation strips away the organic, collaborative learning that occurs when students cross-reference answers or discuss concepts in real-time.

For classroom implementation, this suggests that while traditional mobile platforms remain highly effective at naturally facilitating collaborative, group-oriented, and socially distributed learning dynamics,

VR artifacts are optimal for solitary, highly focused experiential modules. Future research should explore multi-user networked VR environments to bridge this gap, capturing the cognitive benefits of immersion without sacrificing social connectedness.

Importantly, participants across both groups recognized the baseline pedagogical utility of the trivia framework. They also identified consistent areas for systemic refinement, emphasizing the necessity of an expanded question database and more immediate, formative feedback mechanisms. Incorporating these user-driven suggestions alongside more complex environmental interactions will form the baseline of future developmental iterations.

Finally, while the engagement and immediate performance metrics captured in this study are promising, they do not constitute direct measures of long-term knowledge retention. Additionally, because the VR condition introduced multiple unique design elements, such as 3D interactive objects, an avatar companion, and a rich forest environment, the positive results cannot be attributed strictly to the VR technology alone, as these variables were not isolated independently. Nevertheless, these insights provide a crucial foundational understanding of player psychology and interaction dynamics within the VR Trivia World Quest ecosystem. Our findings demonstrate that VR-based trivia games have substantial potential to outpace traditional mobile platforms in driving user engagement. Future longitudinal research should build on these findings to evaluate long-term knowledge retention while systematically isolating the specific effects of environmental design, virtual companionship, and the underlying technological medium.

7. Limitations and Future Work

The findings of this study should be considered in light of several limitations, which also highlight valuable avenues for future research.

First, this project is just the first step in an ongoing, iterative process and further studies with larger and more diverse sample groups are essential to gather more comprehensive data and fully validate our findings. Gender-balanced groups are necessary to ensure gender effects don't skew spatial preference or engagement behaviors."

Second, hardware constraints necessitated distinct operational setups between conditions. While the mobile condition allowed all 24 participants to play simultaneously in the classroom, the VR condition relied on a pool of four headsets, requiring sequential rotations of four participants at a time (supplemented by battery charging and sanitization protocols). Consequently, classroom density and concurrent play differed: 24 active mobile users created a naturally higher

probability for spontaneous peer interaction compared to the VR sessions, where only four students were immersed simultaneously. While HMD sensory occlusion inherently reduces environmental social interaction, this staggered rotation protocol may have further heightened the observed gap in peer dynamics between conditions.

Although monetization wasn't included in this prototype, finding the right financial model is a compelling idea worth exploring to ensure long-term viability and attract investment. For the general market, future work could look into premium features like unlockable question packs and new environments, or adapt the tool for specialized training. Concurrently, it is highly worthwhile to explore affordable solutions in the school context, such as institutional licensing, educational grants, or tech subsidies, to assess how these apps can realistically fit within tight school budgets.

Additionally, the significant *Time × Group* interaction effect must be conditioned by initial baseline differences. The mobile group had a higher pre-test score ($M = 9.30, SD = 4.90$) than the VR group ($M = 6.70, SD = 2.31$). This introduced a potential ceiling effect for the mobile condition, which artificially truncated its potential delta variance. Because mobile participants started closer to the maximum score, their upward trajectory was structurally constrained by the instrument scale. Conversely, the VR group's lower baseline provided a wider empirical runway to demonstrate gains. This steeper slope represents a release from the control group's ceiling limitations rather than a release from any hypothetical floor constraints on the VR group itself. Future studies should use more granular scales to ensure equivalent baseline variance.

Finally, while participant satisfaction was encouraging, tracking long-term content knowledge retention was outside the scope of this study. Future research needs to include a delayed post-test, such as a two-week follow-up, to understand if and how knowledge retention declines over time. Along with this, future studies must find better strategies to minimize participant attrition and ensure students do not miss these critical late-stage testing windows.

8. Conclusion

This paper examines the functional and psychosocial factors that contribute to participants' satisfaction and enjoyment with a virtual reality (VR) and mobile trivia game. We also compare these tools, as their effects on the learning outcomes of teens from two public schools. Quantitative and qualitative findings revealed positive outcomes in several dimensions like audiovisual appeal, perception of future educational value, immersion, control and enjoyment. Each dimension can

provide more accurate insights into its benefits for the effectiveness of VR trivia games as an edutainment tool. In this sense, the positive results showcase that VR trivia games can potentially enhance learning content, increasing user satisfaction and motivation.

The results also showcased the benefits of a collaborative effort between academia and industry. Industry gained an analytical perspective on related work, creating opportunities for novelty and effective design approaches. The game system was studied, evaluated, assessed, and validated across various dimensions, and the gathered feedback can be used for refinements and improvements. The investigator utilized the system as an artifact to conduct Research Through Design, enabling research at different stages of the game's design and development. This can lead to future longitudinal studies across various settings, thereby expanding the research in this area.

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References

- [1] Petersen GB, Petkakis G, Makransky G. A Study of How Immersion and Interactivity Drive VR Learning. *Computers & Education*. 2022;179:104429.
- [2] Guertin-Lahoud S, Coursaris CK, Sénécal S, Léger PM. User experience evaluation in shared interactive virtual reality. *Cyberpsychology, Behavior, and Social Networking*. 2023;26(4):263-72.
- [3] Abeelee VV, Spiel K, Nacke L, Johnson D, Gerling K. Development and validation of the player experience inventory: A scale to measure player experiences at the level of functional and psychosocial consequences. *International Journal of Human-Computer Studies*. 2020;135:102370.
- [4] Bandura A, Wessels S. Self-efficacy. vol. (4). Academic Press, New York; 1994.
- [5] Vizzotto ADB, de Oliveira AM, Elkis H, Cordeiro Q, Buchain PC. Psychosocial characteristics. In: *Encyclopedia of behavioral medicine*. Springer; 2020. p. 1794-5.
- [6] Tisza G, Zhu S, Markopoulos P. Fun to Enhance Learning, Motivation, Self-efficacy, and Intention to Play in DGBL. In: *Entertainment Computing–ICEC 2021: 20th IFIP TC 14 International Conference, ICEC 2021, Coimbra, Portugal, November 2–5, 2021, Proceedings* 20. Springer; 2021. p. 28-45.
- [7] Pelletier C. Games and Learning: What's the Connection. *International Journal of Learning and Media*. 2009;1(1):83-101.
- [8] Hubert-Wallander B, Green CS, Bavelier D. Stretching the limits of visual attention: the case of action video games. *Wiley interdisciplinary reviews: cognitive science*. 2011;2(2):222-30.
- [9] Shin DH. The evaluation of user experience of the virtual world in relation to extrinsic and intrinsic motivation. *International Journal of Human-Computer Interaction*. 2009;25(6):530-53.
- [10] Merhi MI, Meisami A. The Role of Technological and Motivational Factors on Students' Satisfaction with E-learning Assessments Platforms. *Pacific Asia Journal of the Association for Information Systems*. 2024;16(3):4.
- [11] Leontyeva A, Schnittke E. The use of authentic games in teaching L2 Russian grammar. In: *Dynamic Teaching of Russian*. Routledge; 2023. p. 81-106.
- [12] Ouyang A, Gadiraju M, Gadiraju V, Power L, Gadiraju V, Liu G, et al. GRAPES: Trivia game increases sickle cell disease knowledge in patients and providers and mitigates healthcare biases. *Pediatric Blood & Cancer*. 2022;69(7):e29717.
- [13] Walsh KR, Pawlowski SD. Virtual reality: A technology in need of IS research; 2002.
- [14] Sanchez-Vives MV, Slater M. From presence to consciousness through virtual reality. *Nature reviews neuroscience*. 2005;6(4):332-9.
- [15] Bond M, Marin VI, Dolch C, Bedenlier S, Zawacki-Richter O. Digital transformation in German higher education: student and teacher perceptions and usage of digital media. *International journal of educational technology in higher education*. 2018;15(1):48.
- [16] Lampropoulos G, Keramopoulos E, Diamantaras K, Evangelidis G. Augmented reality and virtual reality in education: Public perspectives, sentiments, attitudes, and discourses. *Education Sciences*. 2022;12(11):798.
- [17] Devi KS. Constructivist approach to learning based on the concepts of Jean Piaget and Lev Vygotsky An analytical Overview. *Journal of Indian Education*. 2019;44(4):5-19.
- [18] Kolb DA. *Experiential learning: Experience as the source of learning and development*. FT press; 2014.
- [19] Bloom BS. *Taxonomy of educational objectives: Handbook II*. David McKay; 1956.
- [20] Gilakjani AP, et al. Visual, auditory, kinaesthetic learning styles and their impacts on English language teaching. *Journal of studies in education*. 2012;2(1):104-13.
- [21] Hartsock JM, Lange RH. Trivia games: stimulating student learning. *Nurse Educator*. 1987;12(1):24-7.
- [22] Nuci KP, Tahir R, Wang AI, Imran AS. Game-based digital quiz as a tool for improving students' engagement and learning in online lectures. *IEEE Access*. 2021;9:91220-34.
- [23] Kurniawan AEH, Nugroho AC, Prasetya F. Tank Battle And Trivia Quiz Games Development Using Construct 2

- To Improve Critical Thinking Ability. *journal of business and technology*. 2023;3(2):74-81.
- [24] Licorish SA, George JL, Owen HE, Daniel B. "Go Kahoot!" enriching classroom engagement, motivation and learning experience with games. 2017.
- [25] Kahoot!. Kahoot! Learning Platform; 2026. <https://kahoot.com/>.
- [26] Moutinho A, Sá S. Implementing active learning through pedagogical coaching in Control Systems lectures. In: 2018 3rd international conference of the Portuguese society for engineering education (CISPEE). IEEE; 2018. p. 1-6.
- [27] Sweller J. Cognitive load theory and educational technology. *Educational technology research and development*. 2020;68(1):1-16.
- [28] Ryan RM, Deci EL. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American psychologist*. 2000;55(1):68.
- [29] Reer F, Wehden LO, Janzik R, Tang WY, Quandt T. Virtual reality technology and game enjoyment: The contributions of natural mapping and need satisfaction. *Computers in Human Behavior*. 2022;132:107242.
- [30] Unity Technologies. Unity Real-Time Development Engine; 2026. <https://unity.com/pt>.
- [31] Meta. Meta Quest Virtual Reality; 2026. <https://www.meta.com/quest/>.
- [32] Etermax. Trivia Crack. Etermax; 2013. Mobile application. Available from: <https://etermax.com>.
- [33] Skalski P, Tamborini R, Shelton A, Buncher M, Lindmark P. Mapping the road to fun: Natural video game controllers, presence, and game enjoyment. *New Media & Society*. 2011;13(2):224-42.
- [34] Rosenthal R, Cooper H, Hedges L, et al. Parametric measures of effect size. *The handbook of research synthesis*. 1994;621(2):231-44.
- [35] Abrahamson D, Trninic D. Toward an embodied-interaction design framework for mathematical concepts. In: *Proceedings of the 10th international conference on interaction design and children*; 2011. p. 1-10.
- [36] Paas F, Renkl A, Sweller J. Cognitive load theory and instructional design: Recent developments. *Educational psychologist*. 2003;38(1):1-4.
- [37] Song I, Baek K, Kim C, Song C. Effects of nature sounds on the attention and physiological and psychological relaxation. *Urban Forestry & Urban Greening*. 2023;86:127987.

Appendix A: Supplementary Data

Natural Mapping:	The actions used to interact with the game environment were similar to the actions that would be used to do the same things in the real world	The actions used to explore the digital world seem to make sense in the real world	The actions I performed with the controller were closely connected to the actions happening in the game	I felt like I was doing what I wanted to do while performing the different tasks within the game	The controller allowed me to do everything I needed to, to be successful in the game
Audiovisual Appeal:	The graphics make this game more realistic	The graphics and digital environment gave me a sense of serenity	The graphics and digital environment helped me to relax on the quiz questions		
Enjoyment:	I enjoyed playing this video game very much.	I wish I could have played this game longer	I enjoyed playing this game as very interesting	I thought this was a boring activity (Reverse)	This was a fun game I would like to purchase this game
Competence/control	I felt very capable and effective when playing	I am satisfied with my performance in the game	I think I am pretty good at this game.		
Immersion:	To what extent did you experience a sense of 'being' inside the game?	How much did it seem as if you could reach out and touch the objects or environment you saw?	Did the events/people seems to be on a movie screen or more like looking at the events/people through a window ?	It was much more challenging to control myself as a first character than I expected it to be	
Value :	I believe that playing this game could be beneficial to me	I would be willing to do this again because it has some value to me			

Figure 9. psychosocial and functional factors questionnaire

Knowledge Acquisition Questionnaire

1. What is the name of the final of the American football championship?
✓ **Super Bowl**
Big Game, The Game, The Final
2. Which President of the Portuguese Republic was assassinated in 1918?
✓ **Sidónio Pais**
Canto e Castro, Bernardino Machado, António José de Almeida
3. What is the capital of Malawi?
✓ **Lilongwe**
Lomé, Lusaka, Malabo
4. In what year did the Hundred Years' War begin?
✓ **1337**
1385, 1415, 1420
5. In what units is electrical resistance measured?
✓ **Ohm**
Hertz, Volt, Ampere
6. The Christ the Redeemer statue in Rio de Janeiro is one of the 7 wonders of the world; what is its height?
✓ **38 meters**
21 meters, 50 meters, 102 meters
7. In what year was the poetic work by writer Luís Vaz de Camões, "The Lusiads," first published?
✓ **1572**
1580, 1496, 1524
8. Arkose is...
✓ **A sedimentary rock**
A rheumatic disease; A figure of speech; A deviation of a spinal vertebra.
9. Which of these countries does not border Mozambique?
✓ **Botswana**
Zambia, Malawi, Eswatini (Swaziland)
10. What is a "Lustro"?
✓ **A period of 5 years.**
A famous person; An instrument for polishing/shining; An object that shines.

11. Which of the following works was written by José Saramago?
✓ The Stone Raft (A Jangada de Pedra)
Os Nós e os Laços, Recordações da Casa Amarela, Uma Abelha na Chuva

12. In which sea is the Antilles archipelago located?
✓ Caribbean Sea
Dead Sea, Black Sea, Caspian Sea

13. What is the largest river on the American continent?
✓ Amazon
Mississippi, São Francisco, Nile

14. In what year did the failed attack on Pope John Paul II occur in Rome?
✓ 1981
1999, 2002, 1985

15. What are the minerals in granite?
✓ Quartz, feldspar, and micas
Feldspar, micas, and augite; Quartz, olivine, and pyroxene; Quartz, feldspar, and pyroxene

16. What is the capital of Madagascar?
✓ Antananarivo
Colombo, Mbabane, Lomé

17. The Strait of Magellan, the maritime passage that honors Ferdinand Magellan, is located:
✓ Between Argentina and Chile
In the Molucca Islands; Between Sumatra and Malaysia; Between Sri Lanka and India

18. Any number (other than zero) raised to the power of zero is equal to:
✓ 1
0, 100, The number itself.

19. Which of the following bones is located in the legs?
✓ Fibula
Humerus, Ulna, Radius

20. Which King succeeded King Sebastian?
✓ Cardinal King Henry I
John III, Philip II, Anthony Prior of Crato

Figure 10. Knowledge acquisition Questionnaire