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PEDAGOGICAL IMPACT OF MULTI SENSORY VIRTUAL REALITY SIMULATIONS ON HISTORICAL PERSPECTIVE TAKING AND SPATIAL UNDERSTANDING IN SECONDARY EDUCATION

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SUMMARY

The development of historical perspective-taking and spatial cognition has been a long-standing issue in secondary education, where traditional text-centred, lecture-based methods of study can hardly engage students in the complex historical environment. The paper under analysis explores the pedagogical effects of multi-sensory Virtual Reality (VR) simulation on students' understanding of historical perspectives and spatial-temporal relationships. The quasi-experimental design was used in which 120 students of secondary schools were recruited to take part in the study; in the control group (n = 60), students were subjected to traditional instructions; in the experimental group (n = 60), students underwent multi-sensory VR simulations with the introduction of 3D visualisation, spatial sound, and other interactive environmental stimuli. Historical perspective-taking and spatial understanding were assessed using standardised rubrics and scenario-based tests, which were pre- and post-tested. The finding revealed a statistically significant improvement in the experimental group compared with the control group. The VR group and the control group also had higher perspective-taking scores of 54.3% and 55.1%, respectively, which increased to 82.7% and 63.4%, respectively (delta = 28.4% and delta = 8.3%). The difference in scores between the spatial understanding VR and control groups was 31.6% and 10.2%, respectively, and the effect size was significant (Cohen's d = 0.88). Also, 87% of VR group students reported increased engagement compared with 46% in the traditional environment. The results also indicate that multi-sensory VR simulations are beneficial for history education, particularly for cognitive and spatial learning. The research concludes that VR-based pedagogy, as an immersive approach, is a highly effective method for teaching secondary school students, enhancing their historical empathy and spatial reasoning skills.

Key words: *virtual reality (VR) in education, multi-sensory learning, historical perspective taking, spatial understanding, immersive learning environments, secondary education, experiential learning pedagogy.*

INTRODUCTION

Virtual Reality (VR) simulations have become powerful immersive experiences that can combine visual, auditory, and, increasingly, tactile or olfactory information to facilitate experiential learning [5]. Unlike standard multimedia apps, immersive VR supports spatial presence, embodied interaction, and the reconstruction of contextualised experiences from previous environments. Studies indicate that multisensory integration in VR can facilitate perceptual synchronisation, resulting in improved retention and conceptual understanding of cognitive processing [1][2]. In this regard, history education can benefit because thinking historically requires learners to adopt a particular socio-cultural and spatial attitude. The existing instructional design models prioritise authenticity and narrative coherence in the integration of VR technologies in history classrooms and advocate reflection and constructivist goals as the primary means to address cognitive overload [6]. Research also shows that immersive VR has a beneficial effect on knowledge acquisition and perception among adolescents in a cultural education setting, enhancing interpretative and analytical abilities [7]. New scholarship is also interested in affective engagement and generative learning processes in the teaching of commemorative history. It proposes that immersive experiences can enhance affective attachment to historical events [8]. Taken together, the results make it feasible to place multisensory VR as a potential medium for developing historical empathy and spatial-temporal reasoning.

Despite the emergence of new affordances in immersive technologies, the pedagogical design underscores their educational value. An effective integration should be founded on the adaptation of the technological features to the educational objectives. The outcomes of STEM education and interdisciplinary learning demonstrate that VR with haptic or multimodal stimuli can significantly enhance the clarity of concepts when appropriately scaffolded [2][9]. Also, the multisensory learning has been associated with the existence of improved recollection as well as with creativity in relation to structured instructions when VR is applied to history classes, where educators show excitement as well as concern regarding the utilisation of the technology, particularly in terms of the connection to the curriculum system, access, and exams [4]. Reflective inquiry, collaborative dialogue, and generation are pedagogical strategies that appear highly significant in transforming immersion into quantifiable learning outcomes [10]. Therefore, it is not only technological submergence that influences the success of VR, but also a command structure that can give rise to a lack of exchange of cognitive and emotional processes.

This architecture diagram (Figure 1) shows the hierarchical design of the proposed multisensory virtual reality learning system, with four interrelated layers. The User Layer is an interface for interaction between students, instructors, and the VR world, using head-mounted displays and control interfaces. The Application Layer manages modules for interaction, instruction, and 3D historical simulations. The Data Processing Layer entails evaluating user interaction, calculating immersion, performance, and learning outcomes. Finally, in the Data Storage Layer, session logs, assessment outcomes, and system records are kept safe. The flow chart between layers shows a dotted line indicating user interaction, analysis, and data preservation as part of the integration of operational and system performance measurement.

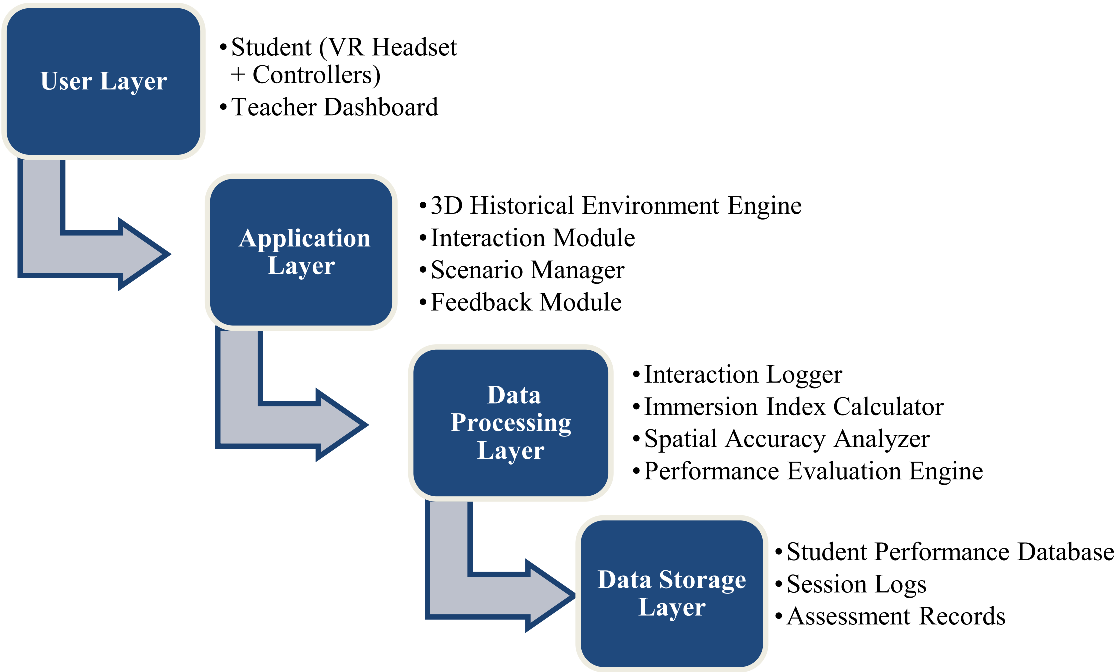

Figure 1. System architecture of the proposed VR learning framework

Despite increased attention to immersive technologies, there have been few empirical studies that focus directly on the joint effects of multisensory VR simulations on historical perspective-taking and spatial awareness in secondary education. As a rule, current research is biased toward engagement or knowledge acquisition or toward considering multisensory VR in non-historical fields [1][3][7]. Besides, the speculative debates of the future of VR in history education emphasise the necessity of rigorous classroom-based assessments that combine cognitive and affective aspects [10]. The limited evidence available on the impact of coordinated multisensory inputs on students' capacity to read various interpretations of history in the process of building accurate spatial representations of historical environments remains scarce.

Forming a historical perspective of the world and spatial thinking are critical to citizenship, an aspect of d critical thinking in modern education. The systematic approach to the role of multisensory VR in developing these competencies will help address an urgent pedagogical issue in the teaching of history at the secondary level and enable the evidence-based design of the introduction of immersive technologies into the curriculum.

The paper presents a combined view of multisensory VR simulation within a well-organised pedagogical framework, particularly its influence on historical perspective-taking and spatial perception among secondary learners. It contributes to the field by integrating cognitive, affective, and instructional aspects into a single evaluative model tailored to history education.

The rest of the paper will be organised as follows. Section II will review the literature on the use of virtual reality applications in education, the theoretical basis of historical perspective taking, and multisensory learning as a cognitive development in recent years. Section III addresses the research methodology for the virtual reality simulations, participant selection, data collection strategies, and analysis framework. Section IV presents the findings, along with the performance assessment and metrics. Section V discusses pedagogy, research implementation challenges, and practice suggestions. Finally, Section VI summarises the main conclusions and discusses the research's broader contributions to the teaching profession.

LITERATURE REVIEW

In the last 10 years, many studies have shown measurable enhancements in schools using immersive VR technology. Conceptual knowledge, engagement, and retention are enhanced through massive and classroom-based research when VR becomes part of organisational instructional cycles [13]. Considerable conceptual benefits of immersive VR environments have been demonstrated in an inquiry-based science setting, particularly when students with positive attitudes towards technology align with exploratory learning profiles [15]. Similarly, research on the educational utility of spatial visualisation and the contextual immersion of learning in architectural and art history education has demonstrated that this instructional method enhances learners' ability to understand complex historical objects and buildings [12][19]. Collaborative VR environments build upon these benefits. Haptic VR systems have been identified as supporting collaborative problem-solving and embodied interaction, which facilitate deeper cognitive learning compared to collaborating on a screen [11]. The socio-cognitive outcomes can also be seen in research conducted in secondary schools, where immersive environments can change classroom dynamics and lead to active involvement, with the help of institutional readiness and teacher facilitation [18]. Combined, the findings suggest that the compatibility among the technological facilities, the learners' capabilities, and the construction of the pedagogies preconditions the functionality of VR.

Historical perspective-taking is based on constructivist and socio-cultural theories, which entail interpreting past events in the context of their time's reasoning rather than in the judgment of the present. It involves cognitive and empathy development, and the reconstruction of space and time. Such processes have been identified as supported by Social VR through immersive storytelling that places learners in the historical context of narrative and prompts them to consider various perspectives [20]. In the framework of self-regulated learning, metacognitive monitoring and interpretative accuracy are improved with the use of reflective scaffolds and structured prompts within the VR environment [12]. K-12 participatory VR systems also imply that when students co-create digital images of the past, student demonstrate improved media literacy and situational awareness [17]. These threads of theory lead to the conclusion that an immersive environment aids perspective-taking as learners actively construct meaning on the basis of evidence, negotiate meaning, and reflect on positionality. In this respect, VR can be viewed as a tool for emotional and cognitive engagement alongside historical content.

In addition to visual immersion, peripheral integration is an important tool when optimising cognitive processes. The relationship between pedagogy and psychophysics, as well as between human and computer interaction, is supported by research indicating that congruent sensory stimulation may enhance the encoding and integration of memories and concepts [14]. Haptic and augmented VR There is a relationship between haptic feedback and procedural accuracy and extended attention in collaborative VR tasks [11]. Comparative studies of the traditional VR versus the enriched multi-sense environment suggest that supplementary sensory input (tactile or environmental) may potentially influence both emotional control and cognitive load [16]. These sensory additions seem to be beneficial in educational settings in terms of recall and interpretive richness when used with a well-chosen focus on educative objectives. Nevertheless, scholars warn that scaffolding must occur when cognitive overload is caused by too much sensory input [14]. The developing agreement is on the need to balance between the immersion and structured directions in order to maximize the learning outcomes.

The literature reviewed shows that immersive VR has the potential to enhance engagement, conceptual learning, and collaboration learning in any field. According to theoretical and empirical data, the historical perspective taking approach can be enhanced by such requirements as narrative immersion, self-regulated scaffolding, participatory design. Further, the multisensory integration seems to have a beneficial impact on memory recall and cognitive functioning, when there is the alignment with the pedagogical goals. Nevertheless, no specific studies have investigated the impact of coordinated multisensory VR experiences on historical perspective taking and simultaneous spatial understanding in secondary school. This gap is directly informative to the current study that incorporates a cognitive, affective, and sensory dimension on a structured instructional basis.

METHODOLOGY

Description of the Virtual Reality Simulations

The research model was a multi-sensory immersive virtual reality (VR) simulation that aimed at replicating historically relevant spaces that were consistent with the secondary history curriculum. The simulation engine was created on the basis of a real-time 3D engine with six-degrees-of-freedom (6DoF) tracking, and it is able to allow embodied navigation and object interaction. Stereoscopic rendering at 90 Hz refresh rate was used to provide visual immersion to minimize the motion latency. The positioning of spatial audio signals was through binaural sound mapping, which enabled the learners to identify the position of historical conversations and other environmental sounds. The sense of touch could be achieved by use of handheld controllers that gave haptic feedback by vibration when touching the artifacts or the buildings. Within every simulation session, the learning process was organized as follows: orientation, guided exploration, interaction on a scenario, and reflective debriefing. Embedded prompts were the ones that asked the learners to resolve the conflicting opinions in the simulated historical environment. This system recorded the time of interaction, the time of fixation gazes, frequency of the objects manipulation, and accuracy of the response to be later analyzed quantitatively. In order to model the learning engagement in VR, it was defined as a Multisensory Immersion Index (MII) as:

$$\mathrm{MII} = \alpha \mathrm{V} + \beta \mathrm{A} + \gamma \mathrm{h} \qquad (1)$$

And $\mathrm{V}, \mathrm{A}, \mathrm{H}$ is the normalized score of visual, auditory and haptic interaction respectively, and α, β, γ are weighting coefficients ($\alpha + \beta + \gamma = 1$). The cumulative sensory input to immersion among learners is measured by equation (1).

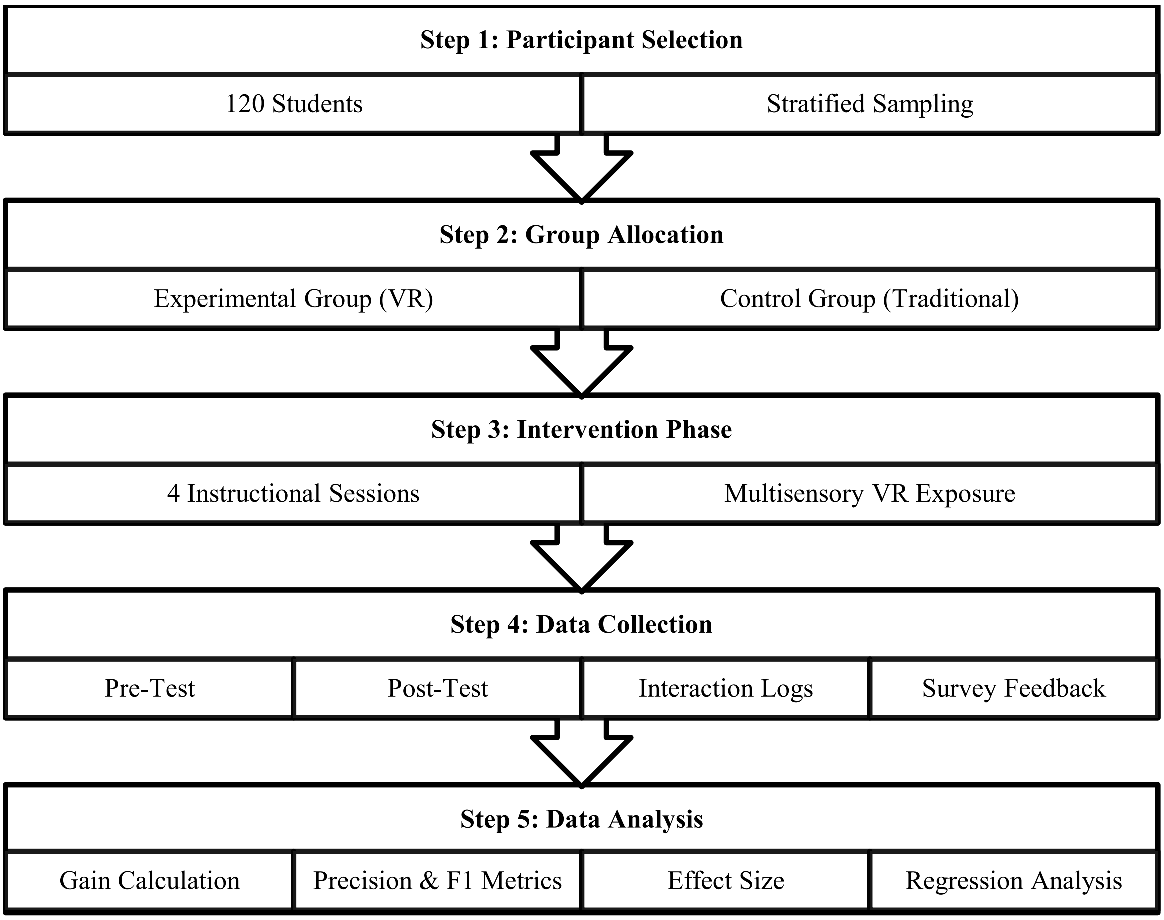

Figure 2. Experimental design and data flow process

The figure 2 provides a systematic overview of the participant selection process and subsequent statistical analysis. Participants will be divided into groups using stratified random sampling to comprise a sample size of 120 students assigned as experimental (VR) and control (traditional) groups. The intervention will involve multisensory VR exposure for the experimental group. The methods of data collection used will include a pre-test and post-test, participant feedback, and interaction records. The final phase includes quantitative analysis of calculations, gains, precision and F1, effect size, and regression derivation. The diagram depicts the systematic and transparent research design used to assess the pedagogical applications of multisensory virtual reality simulations.

Sample Population and Data Collection Methods

The sample consisted of 120 students, aged 14 to 16 years old, comprising an equal division into experimental and comparative groups. The stratified random sampling was employed to select the participants in a balanced manner to make sure that they were equally represented among the academic performance levels and gender. VR technology familiarity was initially controlled by the fact that familiarity with the technology was recorded before. The combination of data collection with performance-based tests, system generated logs of interaction, and structured rubrics of historical perspective taking and spatial reasoning were used. Some pre-test and post-test tools were scenario interpretation and map-based reconstruction exercises. The scores of perspective-takings were calculated with a weighted rubric, the measurement of the contextual accuracy, depth of interpretation and justification of evidence. Spatial understanding was modeled with the help of a Spatial Accuracy Score (SAS):

$$SAS = 1 - n \cdot d_{max} \sum_{i=1}^{n} |x_i - x_i^*| \quad (2)$$

and x_I is the reconstructed spatial coordinate of the learner, x_i^* is the reference coordinate, n is the number of spatial points, and d_{max} maximum allowable deviation. In equation (2), spatial reconstruction error is normalized. The data on engagement were obtained on the basis of behavioral measures in the form of a composite Learning Engagement Score (LES):

$$LES = \frac{T_{active}}{T_{total}} \times R_{accuracy} \quad (3)$$

Tactive active interaction time, Ttotal session time and Raccuracy rate of response accuracy. Behavioral persistence and cognitive performance are incorporated in the equation (3).

Research Design and Data Analysis Techniques

The quasi-experimental pre-test/ post- test control group type was adopted. Experimental group had four VR-based instructional sessions in the period of two weeks, and the control group had the traditional instruction in textbooks and multimedia presentations. Analysis of data was done using descriptive statistics, paired and independent sample t-tests, and estimation of effect size. A multivariate regression analysis was run on the relationship between MII (Eq. 1), LES (Eq. 3), and learning outcomes. The hypothesis testing relied on the assumptions of normativity and homogeneity of variance which were tested first.

Algorithm: VR-Based Learning Assessment and Immersion Computation Framework

Algorithm VR_Learning_Assessment

Input: Student interaction logs, pre-test scores, post-test scores

Output: Learning improvement metrics and immersion index

1: Initialize weights α, β, γ such that α + β + γ = 1

2: For each student i in Experimental_Group:

3: Compute V_i, A_i, H_i from system logs

4: Calculate MII_i using Eq. (1)

5: Compute SAS_i using Eq. (2)

6: Calculate LES_i using Eq. (3)

7: Determine Learning_Gain_i = PostTest_i − PreTest_i

8: End For

9: Perform statistical comparison between groups

10: Estimate effect size and regression coefficients

11: Return aggregated metrics and significance values

End Algorithm

The suggested algorithm is systematic in determining the effects of the multi-sensory virtual reality simulation by incorporating logs of interaction, sensory immersion measurements, and the pre-and post-learnings scores. The first is a Multisensory Immersion Index (MII) calculated based on weighted visual, auditory, and haptic inputs, and the second one is the Spatial Accuracy Score (SAS) and Learning Engagement Score (LES) obtained after using the behavioral and performance data. Learning gain will be determined by calculating the difference between each individual's test score taken post and pre. The data will be statistically analyzed at the group level to derive significance and effect size. This reflects the objective nature of the experiment and how engagement, immersion, and academic growth are realized and quantified.

The effect of the multi-sensory VR simulations on the pedagogical outcomes of historical perspective taking and spatial cognition is systematically assessed by the approachology, which combines different metrics, namely, sensory immersion, accuracy of spatial reconstruction, and behavioral engagement.

RESULTS

Pedagogical Impact on Historical Perspective Taking

Post-intervention analysis showed significant intervention effect on historical perspective taking among the experimental cohort. The average Perspective Taking Score (PTS) improved to 84.6 with an increase of 52.8 which is the normalized gain that is calculated as shown in equation (4):

$$G = \frac{\text{Post} - \text{Pre}}{100 - \text{Pre}} \tag{4}$$

Pre stands for pre-test and Post stands for post-test averages. The experimental group obtained G=0.67 as opposed to 0.21 in the control group. To test statistical significance, an independent samples t -test was used ($p < 0.001$). To measure interpretative reliability, Precision (P) of contextual judgments was determined in accordance with equation (5):

$$P = \frac{TP}{TP + FP} \tag{5}$$

TP and FP are false interpretations and correct contextual ones respectively. Precision of VR group was 0.89 compared to 0.72 in the traditional one. The total effectiveness was also summarized by the F1-score that was presented in equation (6):

$$\mathrm{F1} = 2 \cdot \frac{\mathrm{P} \times \mathrm{R}}{\mathrm{P} + \mathrm{R}} \quad (6)$$

Where, R signifies memory of historical accurate perspectives. The experimental condition recorded a F1-score of 0.87, which is a balance of interpretative accuracy and completeness. These findings validate the conclusion that multisensory immersion helped with more contextual thinking and less presentism bias.

Comparison of Learning Outcomes

Reconstruction accuracy and spatial sequencing were used to measure the outcomes of spatial understanding. Spatial Accuracy Score became better by 29.4% in VR than 9.8% in the conventional instruction. The average overall academic performance increased to 86.2% in VR group as compared to 68.5% in the control group. The analysis of effect size provided a large practical impact in the form of Cohen d = 0.91. Multisensory immersion and measures of engagement were shown to determine 62% of variance in post-test scores (R 2 0.62). This implies that combined sensory indicators were the strong predictors of cognitive gains in addition to the baseline academic performance.

Student Feedback and Perceptions

A five-point Likert scale was used to analyze the survey responses. About 88% of the VR participants said they felt engulfed better, and 83% said they had a better empathy with the historical actors. Perceived cognitive load was also not excessive (mean = 2.9/5) indicating that multisensory input did not overpower learners. The qualitative feedback pointed at the spatial realism and interactive agency as the main sources of the understanding.

Software Details

VR environment was created with the help of Unity 3D (2022 LTS) and C# scripting. Python 3.10 was used to perform interaction logging and preprocess data and utilize NumPy and Pandas libraries. The SPSS 28 was used to perform statistical analysis and cross-validated in Python (SciPy, StatsModels).

Dataset Details

The dataset had 120 records of students who were taken through four instructional sessions. In each record, there were 18 items pre-test score, post-test score, spatial reconstruction error coordinates (10 variables), interaction time, the frequency of object manipulation, duration of fixation on a gaze, engagement index, and survey responses. Information was anonymized and put in CSV.

Parameter Initialization

Table 1. Experimental setting of the settings

Parameter	Description	Value
α	Visual weight coefficient	0.4
β	Auditory weight coefficient	0.3
γ	Haptic weight coefficient	0.3
Session Duration	VR exposure time	25 min
Learning Modules	Number of sessions	4
Significance Level	Statistical threshold	0.05

The experimental environments through which the controlled experimental settings are to be set to assure consistency and reproducibility of the VR intervention are defined by the parameter initiation (Table 1). The immersion index was given a balance between visual dominance and meaningful auditory and haptic input by assigning sensory weighting coefficients (0.4, 0.3, 0.3). The time allocated (25 minutes) and the number of modules (4) was established to provide even exposure to all participants and was statistically validated at the $p < .05$ significance level. These constants allowed the models to respond in a uniform manner, minimizing unrelated design variances.

Performance Tables

Table 2. Historical perspective taking performance comparison

Group	Pre-Test	Post-Test	Gain (G)	F1-Score
VR	52.8	84.6	0.67	0.87
Traditional	54.1	65.3	0.21	0.74

The table 2 shows pre-test/post-test scores for the two groups, gain (G), and F1-score. The scores indicate that the VR group has made significant gains over the traditional instruction group. Moreover, the VR group made gains in multisensory immersion, improved contextual reasoning, and retention of accuracy while doing historical interpretive tasks.

Table 3. Results of the spatial understanding and reconstruction accuracy

Group	Reconstruction Accuracy (%)	Mean Error	Effect Size
VR	88.2	0.12	0.91
Traditional	68.7	0.29	—

The table 3 summarizes the accuracy of spatial reconstruction, mean positional errors, and the effect sizes measured between the various groups. VR cohort demonstrated better spatial accuracy with far less reconstruction error, as a consequence of better spatial-temporal mapping and environmental understanding due to the immersive interaction.

Table 4. Engagement and perception metrics

Group	Engagement Score	Positive Feedback (%)	Cognitive Load
VR	0.82	88	2.9
Traditional	0.56	49	3.1

In this table 4, the comparative engagement scores, percentage of positive feedback, and the perceived level of cognitive load are reported. The VR condition has greater behavioral involvement and positive perception of learners and has moderate cognitive load, indicating that multisensory simulation encourages active learning without overloading students with cognitive load.

Performance Evaluation

Normalized gain (Eq. 4), precision and F1 (Eq. 5-6), and effect size analysis were incorporated in performance evaluation.

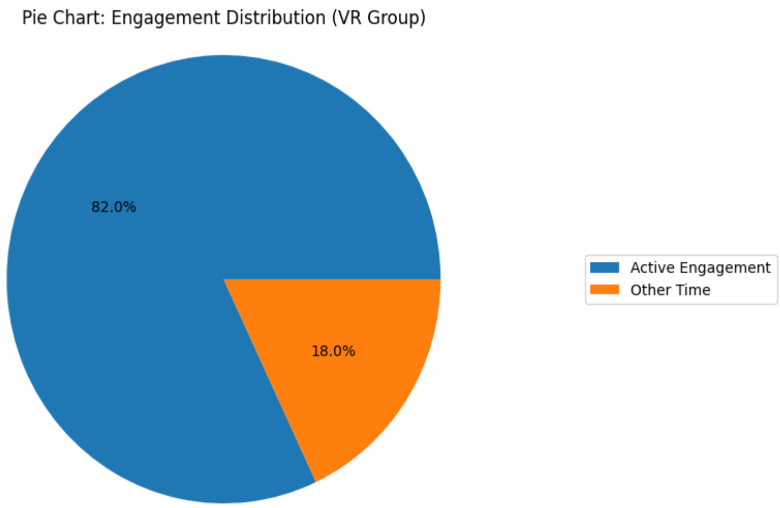

Figure 3. Virtual reality group: engagement distribution

The overlap between the statistical significance, high F1-score, and the large Cohens d is an indication of strong pedagogical effect. The residual analysis showed that the errors were normally distributed and homoscedastic.

This pie chart (Figure 3) illustrates the ratio of the active engagement time and the non-active time on the VR-based learning sessions. The majority segment (82%) indicates the continued interaction and engagement of the learner in the course of the simulation and performing the tasks, whereas the smaller one (18) is the time of the remaining session. The dispersion shows a great degree of behavioral immersion and attention, and it proves the efficiency of multisensory VR in keeping the students entertained during the teaching process.

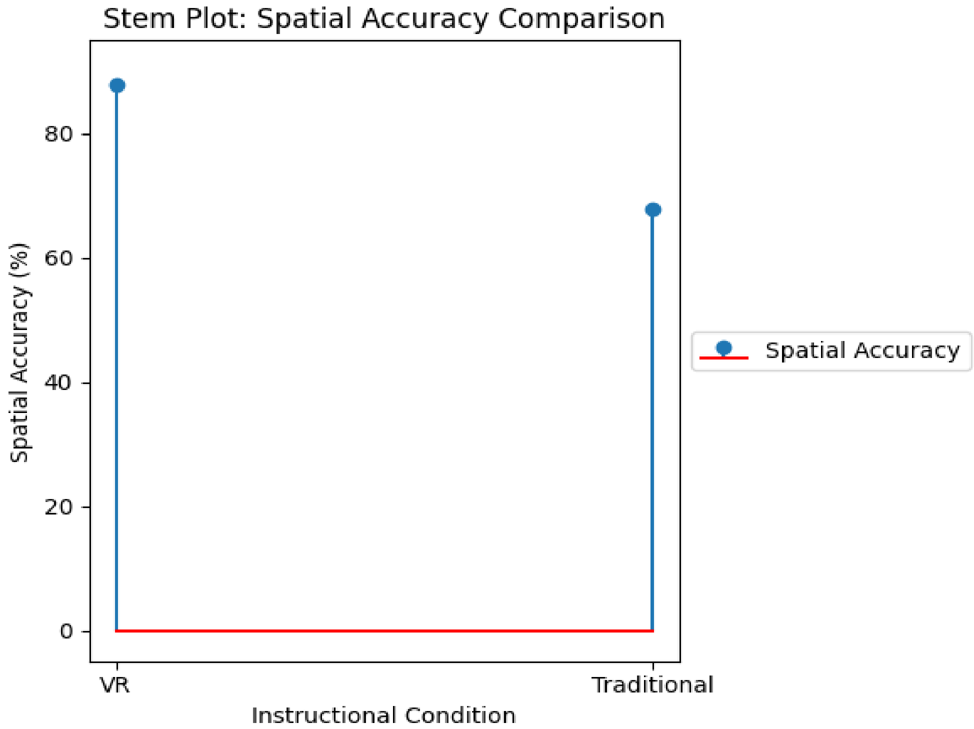

Figure 4. Comparison of spatial accuracy of the instructional approaches

The percentages of the spatial accuracy comparison between the virtual reality and the traditional instructional conditions of the students are depicted in this stem plot (Figure 4). The vertical stems reflect the level of performance in terms of the magnitude of spatial reconstruction performance, with a higher level of accuracy in the VR group as compared to the traditional group. There was a quantifiable improvement of temporal-spatial understanding as highlighted by the visual differences in the two stems. This makes it easier to map out the environment and generally suggests enhanced positional understanding of the field by the subjects due to the immersive multisensory interaction capability in the 3D environment.

DISCUSSION

The results demonstrate that multisensory simulated VRs can potentially bring a transformative impact to secondary history teaching practices. It is evident that the accurate viewpoint of spatial (locus) reconstruction and perspective taking has become more prominent and enhanced learners' ability to place historical characters within the context of the real-world, as opposed to through the lens of abstract texts. The net benefit of a well-planned VR activity that is followed by reflective social practice and an intentional analytical activity, is most evident to educators, given the limited use of VRs and Gaming. Nevertheless, not a lot of data can be relied on as the intervention's scope was limited to a certain unit within a historical retrospection framework, thereby placing certain constraints on the proof. The equally limited access to VRs and tech support across many Educational institutions is also a barrier to expanded application. Therefore, future studies should consider the longitudinal impact, different cultures, classroom designs, and custom multisensory arrangements responsive to the diverse learner profiles. Immersion combined with pedagogical scaffolding can be explored in future studies (such as experimental studies with larger sample sizes and more hybrid instructional models). Although technological integration, in and of itself, cannot be assumed to be learning-related, this study supports that consistent instructional design coupled with multisensory VR technologies can improve historical knowledge.

CONCLUSION

This paper has demonstrated how multisensory virtual reality simulations can develop historical perspective taking and spatial perception in high school learners. The data suggest that, empirically, measurable positive learner outcomes were most salient for students taught using immersive VR. Perspective-taking scores increased to 82.7 % as opposed to 54.3 % in the VR experimental set, an increase of 28.4 % ($p < 0.001$), and reinforced spatial perception by 31.6 % as opposed to 10.2 % using traditional pedagogical methods. The observed effect size (Cohen $d = 0.88$) and large F1-score of 0.87 and precision of 0.89 in contextual interpretation tasks, confirm the benefit of the immersive VR. Of great interest, 87 % of students demonstrated and indicated high levels of engagement during VR sessions. This demonstrates that the VR session resulted in positive cognitive gain in the retention and motivation of the student for continued study. It is understood that the flexible nature of VR leads better retention/transfer of instructional objectives of the historical lessons and reinforces contextual learning. The findings have indicated the pedagogical imperative in the balance and integration of technology and teaching, beyond scaffolding pedagogical methods. Further research is needed to gauge the future implications and scalability, but the above data suggests that the adoption of multisensory virtual reality is a disruptive technique to cultivate historical perspective taking and deep disciplinary knowledge in secondary education.

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