Effectiveness of Virtual Reality-Based Immersive Learning in Improving Basic Volleyball Skills in Physical Education

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Abstract. The integration of immersive technology into physical education has emerged as an innovative approach to enhance motor skill acquisition, student engagement, and interactive learning experiences in sports instruction [1], [2]. This study aimed to develop and evaluate the effectiveness of a Virtual Reality (VR)-based immersive learning application for teaching fundamental volleyball techniques in physical education courses. The research employed a Research and Development (R&D) framework integrated with a quasi-experimental one-group pretest–posttest design. Twenty-five undergraduate students were selected through purposive sampling to participate in the intervention program. The developed VR application simulated essential volleyball techniques, including serving, passing, and blocking, within a three-dimensional interactive environment designed to improve psychomotor performance, spatial awareness, and movement coordination. Data were collected using a standardized basic volleyball skill assessment instrument that measured technical accuracy, movement execution, and coordination ability. Statistical analysis was conducted using paired sample t-tests to determine differences between pretest and posttest scores, while Cohen's d was employed to examine the magnitude of the intervention effect. The findings demonstrated a substantial improvement in students' volleyball performance following the implementation of VR-based immersive learning. The mean pretest score increased from 64.20 to 82.75 in the posttest phase. Inferential statistical analysis revealed a significant difference between pretest and posttest results ($t = 9.12$, $p < 0.001$), indicating that the VR intervention positively influenced students' mastery of basic volleyball skills. Furthermore, the calculated effect size (Cohen's $d = 1.82$) indicated a strong practical effect, suggesting that immersive VR learning provides meaningful contributions to motor learning outcomes. These results support previous studies emphasizing the pedagogical benefits of immersive technologies in sports education, particularly in improving skill repetition, learner motivation, and active participation [3], [4]. The VR-based instructional model offers an engaging and student-centered learning environment that facilitates experiential learning and enhances psychomotor competence. Therefore, integrating Virtual Reality into physical education instruction can serve as an effective alternative teaching strategy for developing fundamental sports skills and advancing technology-enhanced learning in sport science education.

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1 Introduction

Physical education is an integral component of holistic education that contributes to the development of students' physical fitness, psychomotor competence, cognitive understanding, and social interaction skills [1], [2]. In contemporary educational contexts, physical education is not only oriented toward improving physical performance but also toward fostering active lifestyles, collaborative learning, and lifelong health awareness. Within this framework, volleyball represents one of the most widely taught invasion games in school-based physical education because it promotes coordination, agility, reaction time, teamwork, and tactical decision-making [3], [4]. Fundamental volleyball techniques, including serving, passing, and blocking, constitute essential motor competencies that must be mastered to support effective game performance and skill progression [5].

Despite the importance of volleyball instruction in physical education curricula, the teaching and learning process frequently encounters pedagogical limitations. Conventional instructional approaches remain dominant in many educational settings, where teachers primarily employ verbal explanations, demonstrations, and repetitive drill-based exercises [6]. Although these methods may improve basic repetition, they often fail to create meaningful and interactive learning experiences that facilitate students' active engagement and motor understanding. Consequently, many students experience difficulties in comprehending movement mechanics, spatial positioning, and movement coordination during volleyball practice sessions [7].

Motor learning theory emphasizes that skill acquisition is strongly influenced by visual perception, immediate feedback, repetition quality, and learner engagement [8]. In sports education, students require opportunities to repeatedly observe and practice correct movement patterns in order to develop neuromuscular adaptation and procedural memory. However, limited instructional media and inadequate visualization tools frequently hinder students from accurately understanding biomechanical movement execution. This condition reduces learning efficiency and may negatively affect students' motivation and confidence during physical education activities [9].

The rapid advancement of digital technology in the Education 4.0 era has significantly transformed instructional practices across educational disciplines, including sport and physical education [10]. Emerging technologies such as Artificial Intelligence (AI), Augmented Reality (AR), and Virtual Reality (VR) have increasingly been integrated into educational environments to support interactive, student-centered, and experiential learning [11]. Among these technologies, Virtual Reality has gained considerable attention due to its capability to create immersive three-dimensional environments that simulate authentic learning situations and enable users to interact with virtual objects in real time [12].

In the context of sports education, VR-based immersive learning offers substantial pedagogical advantages. Through immersive simulation, students can observe move-

ment demonstrations from multiple perspectives, practice skills repeatedly in a controlled environment, and receive immediate visual feedback regarding movement execution [13]. Previous studies have demonstrated that VR-assisted instruction can improve motor performance, movement accuracy, motivation, engagement, and cognitive understanding in sports training and physical activity learning [14], [15]. Furthermore, immersive learning environments have been associated with increased learner concentration, reduced anxiety during skill practice, and enhanced psychomotor retention [16].

Several recent investigations have confirmed the effectiveness of VR applications in improving sports-related competencies. Radianti et al. [17] reported that immersive virtual environments positively influence learning engagement and experiential understanding in higher education settings. Similarly, recent evidence suggests that VR-supported physical education can improve motor performance, coordination, and student participation when compared with conventional instructional approaches [18]. Nevertheless, research concerning the implementation of VR-based immersive learning specifically for fundamental volleyball instruction remains limited, particularly in school and university physical education contexts in developing countries.

This research gap highlights the need for innovative instructional models capable of integrating immersive technology with motor skill learning in volleyball education. Most previous studies have focused predominantly on general physical education applications, rehabilitation programs, or broad motor-skill interventions rather than on the development and empirical evaluation of VR systems specifically designed for fundamental volleyball techniques [19]. Therefore, further investigation is required to examine how VR-based immersive learning can effectively support psychomotor skill acquisition and improve students' volleyball performance outcomes.

Based on these considerations, this study aims to develop a Virtual Reality-based immersive learning application for basic volleyball instruction and to evaluate its effectiveness in improving students' volleyball skills. The novelty of this research lies in the integration of immersive VR technology into fundamental volleyball learning through an interactive and skill-oriented instructional model. The findings are expected to contribute theoretically to the advancement of technology-enhanced sport pedagogy and practically to the development of innovative instructional strategies in physical education aligned with the demands of Education 4.0.

2 Methods

2.1 Research Design

This study employed a Research and Development (R&D) approach integrated with a quantitative quasi-experimental design to develop and evaluate a Virtual Reality (VR)-based immersive learning application for basic volleyball instruction. The development phase adopted the ADDIE instructional design framework, consisting of Analysis, Design, Development, Implementation, and Evaluation stages, which is widely utilized in technology-enhanced learning research due to its systematic and iterative structure [1], [2]. The integration of the ADDIE model enabled the development of a

pedagogically structured VR application aligned with learning objectives, motor skill characteristics, and student learning needs in physical education contexts.

The effectiveness of the developed application was examined using a one-group pretest–posttest quasi-experimental design. This design was selected to identify changes in students' volleyball skill performance before and after participation in VR-based immersive learning activities [3]. The research framework focused on evaluating the influence of immersive learning environments on psychomotor skill acquisition, movement coordination, and technical execution in volleyball instruction.

The research design can be represented as follows:

Group	Pretest	Treatment	Posttest
Experimental Group	O_1	X	O_2

Where:
O_1 = Initial skill assessment (pretest)
X = VR-based immersive learning intervention
O_2 = Final skill assessment (posttest)

2.2 Participants

The participants consisted of 25 undergraduate students enrolled in physical education courses at the university level. Participants were selected using purposive sampling techniques based on predetermined inclusion criteria. The criteria included: (1) active participation in physical education learning activities, (2) limited mastery of fundamental volleyball techniques, and (3) willingness to participate throughout the intervention period.

The participants were considered relatively homogeneous in terms of age range, educational background, and prior volleyball learning experience. This homogeneity was intended to minimize external variability that could potentially influence the research outcomes. Before data collection, all participants received explanations regarding the objectives and procedures of the study and voluntarily agreed to participate in the intervention program.

2.3 Development of VR-Based Immersive Learning Application

The VR-based immersive learning application was developed to facilitate interactive and experiential learning in basic volleyball instruction. The application focused on the simulation of fundamental volleyball techniques, including serving, passing, and blocking, which represent essential psychomotor competencies in volleyball learning [4].

The development process was conducted according to the ADDIE framework. During the analysis phase, learning needs, instructional challenges, and students' motor skill difficulties were identified through classroom observations and preliminary evaluations. The design stage involved preparing learning scenarios, user interfaces,

movement simulations, and instructional flowcharts adapted to volleyball learning objectives. In the development phase, the VR application was created using three-dimensional (3D) visualization technology to provide immersive and interactive learning experiences.

The VR application enabled students to observe movement demonstrations from multiple perspectives, interact with simulated environments, and repeatedly practice volleyball techniques in a controlled virtual setting. The immersive environment was designed to enhance motor learning through visual feedback, spatial orientation, and repetitive skill execution [5], [6].

To ensure content validity and technical feasibility, the developed application underwent expert validation involving specialists in physical education, volleyball coaching, and educational technology. The validation process evaluated instructional relevance, movement accuracy, interface usability, and technological functionality. Revisions were subsequently conducted based on expert recommendations before implementation in the experimental phase.

2.4 Data Collection Procedure

The data collection process was conducted in three sequential stages, namely pretest, treatment implementation, and posttest assessment.

2.4.1 Pretest

Before the intervention, participants completed an initial volleyball skill assessment to measure baseline performance in serving, passing, and blocking techniques. The pretest instrument evaluated technical execution, movement coordination, body positioning, and skill accuracy. The assessment results were used as baseline data for comparison with post-intervention performance outcomes.

2.4.2 Treatment Implementation

The treatment phase involved the implementation of the VR-based immersive learning application during physical education learning sessions. Participants engaged in structured learning activities using VR simulations designed to facilitate active participation, experiential learning, and repetitive motor practice. During the intervention, students interacted directly with virtual volleyball scenarios, observed correct movement demonstrations, and practiced skill execution in immersive environments.

The intervention program was conducted over several instructional sessions under the supervision of the researcher and physical education instructors. The learning process emphasized student-centered learning principles, motor repetition, and interactive engagement to optimize psychomotor skill acquisition [7].

2.4.3 Posttest

Following the completion of the intervention program, participants completed a posttest using the same volleyball skill assessment instrument administered during the pretest phase. The posttest aimed to evaluate improvements in technical performance and determine the effectiveness of the VR-based immersive learning application in enhancing students' volleyball skills.

2.5 Research Instrument

The primary research instrument used in this study was a standardized basic volleyball skill test designed to assess students' psychomotor performance in serving, passing, and blocking techniques. The assessment criteria included movement accuracy, coordination, balance, reaction timing, and technical execution consistency.

The instrument validity was evaluated through expert judgment involving physical education and volleyball specialists, while reliability testing was conducted using internal consistency analysis. The instrument was considered appropriate for measuring motor skill improvement in volleyball learning contexts.

2.6 Data Analysis

The collected data were analyzed using descriptive and inferential statistical techniques. Descriptive statistics included the calculation of mean scores, standard deviations, minimum scores, and maximum scores for both pretest and posttest results. These analyses were conducted to describe participants' overall performance trends before and after the intervention.

Inferential statistical analysis was performed using a paired sample t-test to determine whether significant differences existed between pretest and posttest scores. The level of statistical significance was established at $\alpha = 0.05$. Prior to hypothesis testing, data normality was examined to ensure compliance with parametric statistical assumptions [8].

To evaluate the practical magnitude of the intervention effect, Cohen's d effect size analysis was additionally conducted. The interpretation of effect size followed Cohen's classification criteria, where $d = 0.20$ indicates a small effect, $d = 0.50$ indicates a medium effect, and $d \geq 0.80$ indicates a large effect [9]. This analysis was intended to provide deeper interpretation regarding the practical effectiveness of VR-based immersive learning in improving volleyball motor skills.

3 Results and Discussion

3.1 Results

Descriptive Statistics

The descriptive statistical analysis revealed a substantial improvement in students' basic volleyball skills following the implementation of the Virtual Reality (VR)-based

immersive learning application. The analysis focused on students' performance in fundamental volleyball techniques, including serving, passing, and blocking.

Table 1. Descriptive Statistics of Pretest and Posttest Scores

Test	N	Mean	Std. Deviation
Pretest	25	64.20	5.35
Posttest	25	82.75	4.90

As presented in Table 1, the mean score increased from 64.20 during the pretest to 82.75 in the posttest, indicating a notable improvement in students' volleyball performance after participating in VR-based immersive learning activities. The reduction in standard deviation from 5.35 to 4.90 also suggests a more consistent level of skill mastery among participants following the intervention. These findings indicate that the VR learning environment contributed positively to students' psychomotor performance and movement coordination.

Inferential Statistical Analysis

To determine whether the observed improvement was statistically significant, a paired sample t-test was conducted to compare pretest and posttest scores.

Table 2. Paired Sample t-test Results

Variable	Mean Difference	t-value	Sig. (2-tailed
Pretest-Posttest	-18.55	-9.12	0.000

The inferential analysis demonstrated a statistically significant difference between pretest and posttest scores ($t = -9.12$, $p < 0.05$). The significance value of 0.000 confirms that the VR-based immersive learning intervention had a meaningful effect on students' volleyball skill development. The mean difference of 18.55 points indicates that participants experienced substantial learning gains after engaging with the immersive VR application.

Effect Size Analysis

To evaluate the practical magnitude of the intervention effect, Cohen's d effect size analysis was performed.

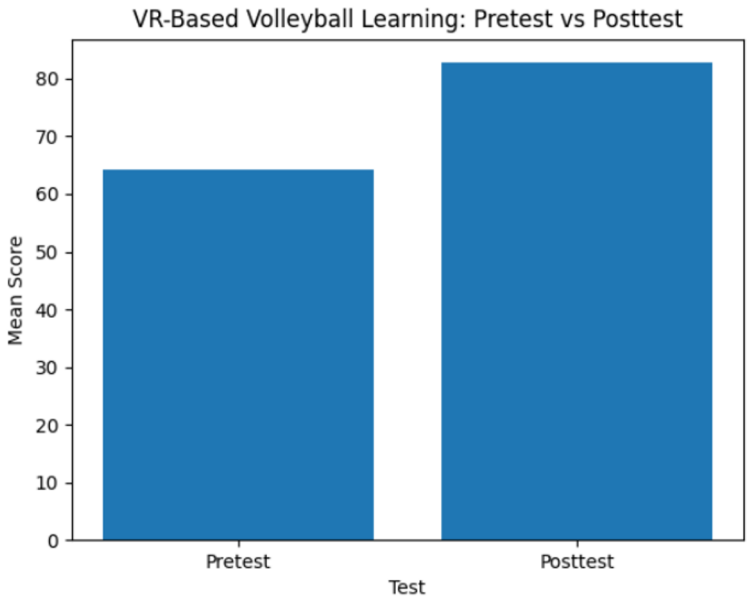
Table 3. Effect Size Analysis

Variable	Cohen's d	Interpretation
Pretest-Posttest	1.82	Large Effect

The obtained Cohen's d value of 1.82 indicates a large effect size according to Cohen's classification criteria [1]. This result demonstrates that the VR-based immersive learning application produced not only statistically significant improvements but also strong practical impacts on students' volleyball skill acquisition. The large effect suggests that immersive learning environments can substantially enhance psychomotor learning outcomes in physical education settings.

Graphical Representation of Learning Outcomes

Fig. 1. Comparison of Pretest and Posttest Mean Scores



The graphical comparison further illustrates the substantial increase in students' average scores after the intervention. The upward trend shown in the posttest scores reflects the effectiveness of immersive VR learning in improving technical execution and movement performance during volleyball instruction.

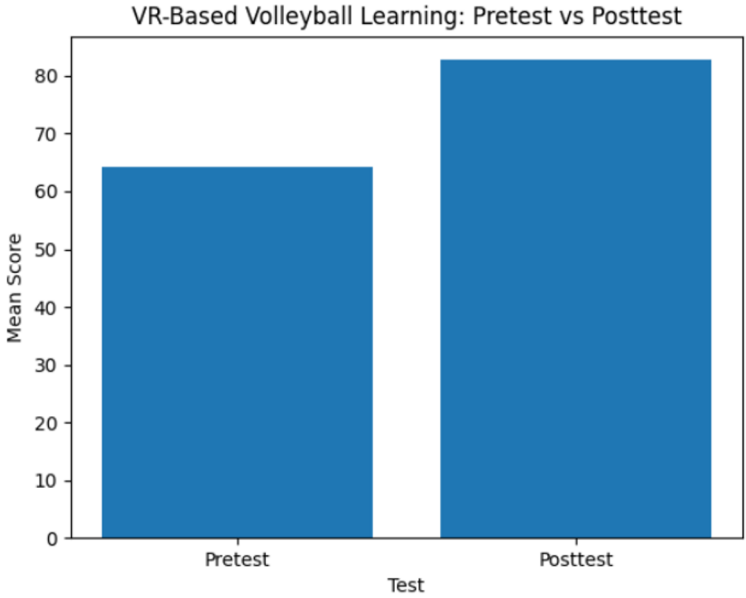


Fig 1. Comprasion of Pretest and Posttest Mean Scores

The bar chart illustrates a clear increase in students' mean scores from pretest to posttest, highlighting the effectiveness of the VR-based learning intervention.

3.2 Discussion

The findings of this study indicate that the implementation of immersive learning through a Virtual Reality-based application significantly improved students' basic volleyball skills. The increase in mean scores, supported by statistically significant paired sample t-test results and a large effect size, demonstrates the effectiveness of VR-assisted learning in enhancing psychomotor performance within physical education contexts.

From a sport pedagogy perspective, the effectiveness of the VR-based learning model can be interpreted through experiential learning and motor learning theories, which emphasize active engagement, repetitive practice, and immediate feedback during skill acquisition [2]. Immersive VR environments allow students to interact directly with three-dimensional simulations that replicate authentic movement situations. Such environments facilitate deeper cognitive processing and improve students' understanding of biomechanical movement patterns in volleyball techniques.

The significant improvement observed in this study aligns with previous research indicating that immersive technologies can positively influence motor coordination, technical execution, and learner engagement [3], [4]. Through VR simulation, students were able to repeatedly practice serving, passing, and blocking techniques in controlled virtual environments without the limitations commonly encountered in conventional physical education instruction. This repetitive and feedback-oriented learning process

contributes to the development of procedural memory and neuromuscular adaptation, which are essential components of motor skill acquisition [5].

Furthermore, the immersive characteristics of VR technology increase students' motivation and concentration during learning activities. Compared with traditional instructional approaches that rely heavily on verbal explanations and repetitive drills, VR-based learning creates more interactive and engaging educational experiences [6]. The realistic visualization provided by the VR application enabled students to observe movement execution from multiple perspectives, thereby improving movement accuracy and spatial awareness during practice sessions.

The large effect size ($d = 1.82$) obtained in this study demonstrates that the intervention had strong practical significance in improving volleyball learning outcomes. This finding suggests that VR-based immersive learning has considerable potential as an alternative instructional strategy in physical education, particularly for teaching fundamental sports techniques requiring visual-motor coordination and repetitive movement practice. The results support previous studies reporting that immersive learning technologies can significantly enhance students' participation, motivation, and psychomotor achievement in sports education [7], [8].

In addition, the findings are relevant to the broader context of Education 4.0, where digital transformation has encouraged the integration of advanced technologies into teaching and learning processes [9]. The implementation of VR technology in physical education reflects the growing need for innovative instructional approaches capable of supporting student-centered and technology-enhanced learning environments. Therefore, integrating immersive VR applications into sports instruction may contribute to improving educational quality and promoting adaptive learning experiences in contemporary physical education.

Despite the positive findings, several limitations should be acknowledged. First, the study employed a one-group pretest–posttest design without a control group, limiting the ability to establish stronger causal relationships between the intervention and learning outcomes. Second, the sample size was relatively small ($N = 25$), which may affect the generalizability of the findings to broader educational populations. Third, the intervention focused only on fundamental volleyball techniques and did not examine long-term retention effects or tactical game performance.

Future research is recommended to employ randomized controlled experimental designs involving larger and more diverse participant groups. Further studies may also investigate the long-term effectiveness of VR-assisted learning, its influence on cognitive and affective learning domains, and comparisons between immersive VR instruction and other technology-enhanced learning models in sports education.

4 Conclusion

This study demonstrates that the implementation of immersive learning through a Virtual Reality (VR)-based application effectively improves students' fundamental volleyball skills in physical education learning. The effectiveness of the intervention was evidenced by the substantial increase in students' mean performance scores from

pretest to posttest assessments, supported by statistically significant paired sample t-test results ($p < 0.05$) and a large effect size (Cohen's $d = 1.82$). These findings indicate that the VR-based immersive learning model produced both statistical and practical improvements in students' psychomotor performance, particularly in serving, passing, and blocking techniques.

The findings further confirm that immersive VR technology provides an interactive, student-centered, and experiential learning environment capable of enhancing motor skill acquisition, movement coordination, and learner engagement. Through three-dimensional simulation and repetitive skill practice, students were able to better understand movement mechanics and spatial orientation during volleyball learning activities. The immersive characteristics of VR learning also contributed to increased motivation, active participation, and concentration during instructional sessions, which are important factors influencing successful motor learning outcomes [1], [2].

From a sport science and educational technology perspective, this study contributes to the growing body of evidence supporting the integration of immersive digital technologies into physical education instruction. The results indicate that VR-assisted learning can function as an innovative instructional alternative to conventional teaching approaches, particularly in learning contexts requiring visual demonstration, movement repetition, and psychomotor skill development [3]. The integration of VR technology in physical education is therefore aligned with the broader transformation of Education 4.0, which emphasizes technology-enhanced, interactive, and adaptive learning environments [4].

The novelty of this study lies in the development and implementation of a VR-based immersive learning application specifically designed for fundamental volleyball instruction within physical education settings. The study provides practical implications for educators, curriculum developers, and sport practitioners seeking to incorporate immersive technologies into teaching and coaching practices to improve learning effectiveness and student engagement.

Nevertheless, several limitations should be acknowledged. The relatively small sample size and the absence of a control group limit the generalizability of the findings. In addition, the study primarily focused on short-term psychomotor outcomes and did not evaluate long-term retention or tactical performance in competitive game situations. Therefore, future research is recommended to employ randomized controlled experimental designs involving larger participant populations and extended intervention durations. Further investigations may also explore the long-term impact of immersive learning on cognitive, affective, and tactical dimensions of sports education.
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