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Research Article

Effectiveness of Virtual Reality-Based Badminton Simulating In-Game Scenarios on Students' Badminton Performance

Sri Wicahyani[1]*, Abdul Rachman Syam Tuasikal[2], Sapto Wibowo[3], Mochamad Ridwan[4], Supriyono[5], Diva Ristie Valentina[6], Muchammad Arif Krisna Wijaya[7], Alvin Afandi[8], Nandya Rizky Nur Febriana[9]

[1,2,3,4,6,7,8] Physical Education, Faculty Of Sports And Health Sciences, Universitas Negeri Surabaya, Indonesia
[5]Department Of Physical Education, Health, And Recreation, Faculty Of Sport Sciences, Universitas Negeri Semarang, Indonesia
[9]Master Of Exercise, Health And Sport Sciences, Faculty Of Medicine, Universitas Airlangga, Indonesia
* Corresponding Author : Sriwicahyani@Unesa.Ac.Id

Abstract. Badminton instruction in higher education is commonly dominated by isolated technical drills, limiting students' ability to transfer acquired skills into authentic match situations that require tactical awareness and rapid decision-making. This study aimed to develop and evaluate the effectiveness of a Virtual Reality (VR)-Based Badminton Simulating In-Game Scenarios learning model for improving university students' badminton performance. A Research and Development (R&D) approach employing the ADDIE instructional design model was adopted, comprising the phases of analysis, design, development, implementation, and evaluation. The developed VR application was implemented with 24 undergraduate students enrolled in a badminton course using a one-group pre-test–post-test design. Data were collected through expert validation, badminton skill assessment, observation, and student response questionnaires. The normality of the data was examined using the Shapiro–Wilk test, while differences between pre-test and post-test scores were analyzed using the Wilcoxon Signed-Rank Test. The results demonstrated statistically significant improvements in player performance ($Z = -2.718$, $p = 0.007$) and match-winning performance ($Z = -3.051$, $p = 0.002$) following the VR intervention. These findings indicate that the developed learning model effectively enhances badminton performance by providing immersive and representative learning environments that integrate technical execution, tactical awareness, perception–action coupling, and contextual decision-making. This study contributes to technology-enhanced sport education by proposing an innovative VR-based instructional model that extends conventional badminton learning beyond isolated technical practice toward authentic game-based learning experiences.

Keywords: Badminton Learning; Ecological Dynamics; Immersive Learning; Representative Learning Design; Virtual Reality.

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1. Introduction

Badminton is a racket sport that requires the integration of technical proficiency, physical fitness, tactical awareness, and rapid decision-making during dynamic match situations (Phomsoupha & Laffaye, 2015). During competition, players must continuously coordinate body movements, anticipate shuttlecock trajectories, interpret opponents' actions, and execute appropriate strokes within fractions of a second. Therefore, effective badminton instruction should develop not only technical competence but also tactical understanding and adaptive decision-making within representative game contexts (Lin et al., 2021). In higher education, badminton courses play an essential role in preparing future physical education teachers and coaches. However, badminton instruction is still predominantly based on isolated technical drills that emphasize repetitive movement execution rather than contextual game performance. Although this approach improves technical accuracy, it often limits students' ability to transfer acquired skills into authentic match situations. Recent evidence indicates that game-based instructional approaches provide more meaningful learning experiences and improve tactical awareness compared with conventional technique-oriented instruction (Harvey & Jarrett, 2014). A recent systematic review further confirmed that Game-Based Learning and Teaching Games for Understanding (TGfU) consistently enhance decision-making, game performance, and student engagement in badminton learning (Junanda et al., 2025).

The rapid advancement of immersive technology has introduced Virtual Reality (VR) as an innovative instructional medium in sport education. VR enables learners to practice repeatedly within interactive environments that closely resemble real competition while receiving immediate performance feedback (Stone et al., 2022). Such immersive learning environments have been shown to improve motor learning, visual attention, learner engagement, and overall sport performance. In badminton education, VR has also been successfully integrated into learning applications, demonstrating its potential to enrich teaching and learning experiences through interactive simulation (Gazali et al., 2024).

From a pedagogical perspective, effective skill acquisition depends on learning environments that preserve the informational and tactical characteristics of actual competition. Ecological Dynamics explains that sports performance emerges through continuous interactions among the individual, task, and environment (Davids et al., 2013). Building upon this perspective, Representative Learning Design emphasizes that practice activities should replicate competitive situations to strengthen perception–action coupling and maximize skill transfer from training to real match performance (Chow et al., 2023).

Despite increasing interest in technology-assisted badminton instruction, previous studies have primarily focused on wearable technologies, instructional media, or isolated technical skill development. Lin et al. (2021) developed a wearable technology system capable of improving badminton doubles skills through automated movement feedback, whereas Gazali et al. (2024) introduced a Virtual Reality application for badminton referee education. Although these studies demonstrate the educational value of technology integration, they do not provide immersive learning environments that simultaneously develop technical skills, tactical awareness, and contextual decision-making within representative badminton match scenarios.

Consequently, a significant research gap remains regarding the integration of Virtual Reality with representative badminton game simulations grounded in contemporary sport pedagogy. Practice environments that closely resemble actual competition are expected to facilitate more effective learning transfer and improve tactical adaptation during gameplay (Pinder et al., 2011). Furthermore, immersive virtual environments provide opportunities for repeated contextual practice that may enhance both technical performance and decision-making abilities in badminton (Stone et al., 2022).

Therefore, this study aims to develop and evaluate the effectiveness of a Virtual Reality-Based Badminton Simulating In-Game Scenarios learning model for improving university students' badminton performance. The proposed model integrates immersive virtual environments with representative learning principles to create a more authentic badminton learning experience. By combining Virtual Reality technology with realistic match simulations, this study is expected to contribute to technology-enhanced sport education and provide an innovative instructional model that extends beyond conventional technical drill approaches.

2. Literature Review

Badminton Skill Acquisition

Badminton is a complex open-skill sport that requires the integration of technical skills, physical capacity, perceptual ability, anticipation, and tactical decision-making during dynamic match situations (Phomsoupha & Laffaye, 2015)Unlike closed-skill sports, badminton players must continuously adapt their movements according to shuttlecock trajectories, opponents' positioning, and changing game situations. Consequently, successful performance depends not only on mastering fundamental strokes but also on the ability to integrate perception, movement execution, and tactical responses throughout the game.

Fundamental badminton skills include serving, clearing, dropping, smashing, driving, net play, and footwork. However, technical mastery alone is insufficient to achieve competitive performance because players are required to select appropriate strokes according to tactical situations (Lin et al., 2021). Recent movement analysis studies further demonstrate that effective badminton instruction should integrate technical execution with contextual game situations to improve learning transfer and competitive performance (Alexander et al., 2025). Furthermore, skill acquisition in badminton is strongly influenced by repeated exposure to representative game situations rather than isolated movement repetition. Training programs that simulate authentic competition allow learners to simultaneously develop motor coordination, visual perception, anticipation, and tactical awareness, leading to better performance adaptation during actual matches ((Smith et al., 2022).

Game-Based Learning in Badminton Education

The paradigm of sports instruction has shifted from technique-oriented teaching toward learner-centered instructional approaches that emphasize contextual understanding and tactical decision-making. One of the most widely adopted approaches is Teaching Games for Understanding (TGfU), which positions the game itself as the primary learning environment rather than isolated technical drills (Harvey & Jarrett, 2014)

Game-Based Learning enables learners to acquire technical skills while simultaneously developing tactical understanding, communication, and decision-making through representative game situations. Casey & MacPhail (2018) argued that experiential learning within modified games provides richer learning opportunities than repetitive technical practice because learners continuously solve game-related problems.

A recent systematic review conducted by Junanda et al. (2026) concluded that Game-Based Learning and TGfU consistently improve tactical awareness, decision-making, student engagement, and overall badminton performance across different educational settings. These findings indicate that contextual learning environments better facilitate skill acquisition than conventional drill-based instruction. Despite these advantages, implementing Game-Based Learning in higher education remains challenging due to limited facilities, large class sizes, and restricted opportunities to recreate authentic match situations. Consequently, immersive technologies have emerged as promising alternatives for supporting representative badminton learning.

Ecological Dynamics and Representative Learning Design

Ecological Dynamics provides a theoretical framework explaining that sports performance emerges through interactions among individual characteristics, environmental constraints, and task demands (Davids et al., 2013). Within this perspective, learning is not achieved solely through repetitive movement practice but through continuous adaptation to changing environmental information. The Constraints-Led Approach operationalizes Ecological Dynamics by manipulating task, environmental, and performer constraints to encourage learners to discover functional movement solutions independently (Renshaw et al., 2022). This learner-centered approach promotes adaptability and supports the development of individualized movement patterns appropriate for varying competitive situations.

Representative Learning Design extends these principles by emphasizing that practice environments should preserve the informational characteristics of real competition. According to Pinder et al. (2011) representative practice strengthens perception action coupling, thereby improving the transfer of learning from practice to competition. Similarly, Chow et al. (2023) emphasized that representative learning environments encourage athletes to integrate perception, cognition, and movement execution within authentic performance contexts.

Correia et al. (2019) further explained that nonlinear pedagogy encourages learners to adapt their movement strategies according to environmental constraints rather than relying solely on predetermined technical patterns. Therefore, integrating Ecological Dynamics with Representative Learning Design provides a strong theoretical foundation for developing immersive badminton learning environments.

Virtual Reality in Sport Education

Virtual Reality has become one of the most rapidly developing technologies in sport education because it enables learners to experience immersive environments that closely resemble actual competitive situations (Stone et al., 2022). Through three-dimensional visualization and interactive simulation, VR provides repeated learning opportunities without the limitations of physical facilities or opponents. Research has demonstrated that immersive VR improves motor learning, visual attention, movement coordination, and learner motivation across various sports settings (Makransky & Petersen, 2018). Similarly, Wang et al. (2026) reported that mixed reality-based badminton instruction significantly improved visual attention and stroke performance among novice badminton players.

In badminton education, Gazali et al. (2024) successfully integrated VR into referee education, demonstrating that immersive technology enhances learning effectiveness through interactive simulation. These findings indicate that VR has considerable potential to support badminton instruction beyond traditional classroom-based learning. However, the effectiveness of VR depends largely on instructional design. Merely presenting virtual environments is insufficient unless learning activities maintain representative characteristics that encourage tactical thinking, perception–action coupling, and contextual decision-making.

Previous Studies and Research Gap

Previous research has consistently demonstrated positive effects of technology-assisted badminton instruction. Lin et al. (2021) developed a wearable technology system capable of improving badminton doubles skills through automated movement feedback. Alexander et al. (2025) also reported improvements in students' badminton movement skills following VR-assisted learning activities.

More recently, Gazali et al. (2026) found that immersive VR significantly increased learner engagement and enjoyment during badminton instruction, while Wang et al. (2026) demonstrated improvements in visual attention and stroke accuracy through mixed reality-based training. Despite these encouraging findings, previous studies have primarily focused on isolated technical performance, wearable technologies, or instructional media. Very limited research has integrated immersive Virtual Reality with representative badminton match simulations grounded in Ecological Dynamics, Representative Learning Design, and Game-Based Learning principles.

Therefore, the present study addresses this research gap by developing a Virtual Reality-Based Badminton Simulating In-Game Scenarios learning model that simultaneously promotes technical skill acquisition, tactical awareness, perception action coupling, and contextual decision-making within immersive badminton match environments. This integrated approach represents the primary scientific contribution of the present study and extends previous technology-enhanced badminton learning beyond isolated technical instruction toward authentic game-based learning experiences.

3. Proposed Method

Research Design

This study employed a Research and Development (R&D) approach to develop a Virtual Reality (VR)-based badminton learning model entitled Badminton Simulating In-Game Scenarios. The development process adopted the ADDIE instructional design model, consisting of five sequential phases: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected because it provides a systematic framework for developing educational technology products and has been widely applied in sport education and instructional media development.

The research consisted of two major stages. The first stage focused on developing the VR learning model based on instructional analysis and badminton learning characteristics. The second stage evaluated the effectiveness of the developed model through implementation with university students using a one-group pre-test–post-test design, which is appropriate for measuring learning improvements following educational interventions (Thomas et al., 2023).

Participants

All participants signed informed consent before data collection. The participants were 24 undergraduate students enrolled in the Physical Education, Health, and Recreation Program at Universitas Negeri Surabaya. Participants were selected using purposive sampling, a non-probability sampling technique commonly employed when participants possess specific characteristics relevant to the research objectives (Creswell & Creswell, 2023). Participants were inclusion criteria: enrolled in the badminton course; had no musculoskeletal injury during the study; had basic badminton experience; voluntarily agreed to participate.

Development Procedure

The development procedure followed the ADDIE framework.

Analysis

Needs analysis was conducted through classroom observation, interviews with badminton lecturers, and curriculum analysis to identify problems in conventional badminton instruction. The analysis revealed that students experienced difficulties transferring technical skills into actual game situations due to the dominance of isolated technical drills.

Design

Based on the needs analysis, learning scenarios were designed according to the principles of Representative Learning Design and Ecological Dynamics. The scenarios represented common badminton game situations, including: offensive situations; defensive situations; transition play; net play; smash defense; match-point situations. Each scenario contained predefined learning objectives, decision-making tasks, scoring systems, and feedback mechanisms.

Development

The Virtual Reality application was developed using the Unity game engine and optimized for Meta Quest VR Headset. The application integrated 3D badminton courts, opponent animations, shuttlecock trajectories, and interactive game situations. The learning model underwent expert validation involving badminton experts, instructional design experts, and multimedia experts before implementation.

Implementation

Students participated in the VR learning sessions according to the developed scenarios. Each session consisted of orientation, warm-up, VR simulation activities, instructor feedback, and reflection. The intervention was conducted for six weeks with two sessions per week.

Evaluation

Evaluation consisted of formative evaluation during development and summative evaluation after implementation. Product quality was assessed through expert validation and student responses, whereas learning effectiveness was evaluated using pre-test and post-test badminton skill assessments.

Research Instrument

Several instruments were employed in this study: Expert validation questionnaire; Student response questionnaire; Badminton Skill Assessment Rubric; Observation checklist; VR usability questionnaire.The badminton skill assessment evaluated: serve accuracy; clear; drop shot; smash; net shot; tactical decision making. Instrument validity was examined using expert judgment, whereas reliability was analyzed using Cronbach's Alpha.

Data Analysis

Descriptive statistics were used to summarize participant characteristics and questionnaire responses. The normality of the data was examined using the Shapiro–Wilk test, while homogeneity of variance was assessed using Levene's test. Differences between pre-test and post-test badminton skill scores were analyzed using the Wilcoxon Signed-Rank Test, as the data did not satisfy the assumption of normality. Statistical significance was set at $\alpha = 0.05$, and all analyses were performed using IBM SPSS Statistics version 26.

Table 1. Research Variables.

Variable	Indicator	Instrument
Virtual Reality Learning Model	Immersion, interaction, feedback	Expert validation
Badminton Skill	Serve, clear, drop, smash, net shot	Skill assessment rubric
Tactical Ability	Decision making, shot selection	Observation rubric
Student Perception	Usability, satisfaction	Questionnaire

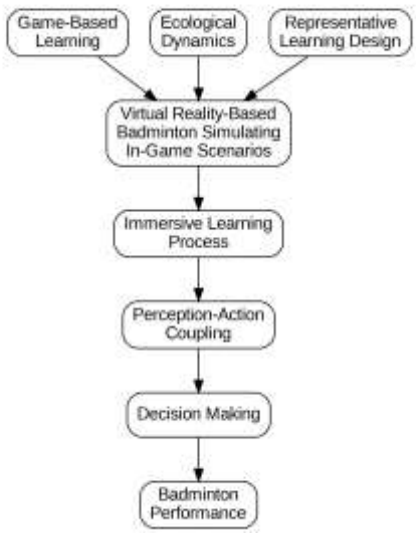

Figure 1. Research Framework.

4. Results and Discussion

Implementation of the VR-Based Badminton Training Program

The Virtual Reality (VR)-based *Badminton Simulating In-Game Scenarios* was successfully developed and implemented using the ADDIE development framework. During the implementation phase, participants first completed a pre-test to measure their baseline badminton skills. They then received an orientation session regarding the VR equipment and simulation procedures before participating in the intervention program. The training consisted of three sequential competitive scenarios in which each participant played two sets against a virtual player. These scenarios were designed to simulate realistic badminton situations requiring rapid decision-making, movement adaptation, and tactical execution. After completing the intervention, participants undertook a post-test using the same assessment procedures to evaluate changes in badminton performance.

Normality Test

The distribution of the collected data was examined using the Shapiro–Wilk normality test. As presented in Table 1, all variables showed significance values below 0.05, indicating that the data were not normally distributed. Therefore, a non-parametric Wilcoxon Signed-Rank Test was selected to determine differences between pre-test and post-test scores.

Table 2. Shapiro–Wilk Normality Test.

Variable	p-value	Interpretation
Player Score (Pre-test)	0.004	Not normally distributed
Player Score (Post-test)	<0.001	Not normally distributed
Winner Score (Pre-test)	<0.001	Not normally distributed
Winner Score (Post-test)	<0.001	Not normally distributed

Effectiveness of the VR-Based Training Program

The effectiveness of the developed VR learning model was analyzed using the Wilcoxon Signed-Rank Test. The results demonstrated statistically significant improvements in both performance indicators. Player scores increased significantly following the intervention ($Z = -2.718$, $p = 0.007$), while the number of winning performances also improved significantly ($Z = -3.051$, $p = 0.002$). Furthermore, the number of positive ranks substantially exceeded the negative ranks, indicating that most participants demonstrated higher scores after participating in the VR-based training program. These findings indicate that the developed simulation effectively enhanced badminton performance among university students.

Table 3. Wilcoxon Signed-Rank Test Results.

Variable	Z	p-value	Interpretation
Player Score	–2.718	0.007	Significant improvement
Match Winner Score	–3.051	0.002	Significant improvement

The findings of this study demonstrate that the developed Virtual Reality-Based Badminton Simulating In-Game Scenarios significantly improved badminton performance among university students. The significant increase in both player scores and match-winning performance indicates that immersive virtual environments provide meaningful learning experiences that extend beyond conventional technical drills. By exposing learners to representative match situations, the developed VR model encouraged students to integrate technical execution with tactical decision-making under dynamic game conditions. Consequently, participants were able to adapt their movement strategies more effectively during simulated badminton matches.

The improvement observed in this study is consistent with previous findings by Lin et al. (2021), who reported that technology-assisted badminton instruction enhanced students' performance through automated movement feedback and contextual practice opportunities. Similarly, Wang et al. (2026) demonstrated that mixed reality-based badminton instruction significantly improved visual attention and stroke accuracy among novice players. These findings indicate that immersive technologies provide richer perceptual information than conventional instructional methods, enabling learners to process game information more efficiently and make more accurate tactical decisions during play. From the perspective of Ecological Dynamics, the developed VR environment strengthened the perception–action coupling process because participants continuously interacted with dynamic game constraints that closely resembled actual badminton competition. Davids et al. (2013) explained that skilled performance emerges through continuous interactions among the performer, task, and environment rather than through repetitive movement execution alone. Throughout the VR simulation, students were required to anticipate shuttle trajectories, recognize opponents' movements, and continuously adjust their positioning and stroke selection according to changing game situations. Such representative interactions likely contributed to the observed improvement in badminton performance.

The present findings can also be interpreted through the Constraints-Led Approach (CLA), which operationalizes the principles of Ecological Dynamics by manipulating performer, task, and environmental constraints to facilitate adaptive skill acquisition. Rather than prescribing fixed movement patterns, the VR-based badminton scenarios encouraged students to explore multiple movement solutions according to changing tactical situations. This adaptive learning process enabled participants to continuously modify their positioning, stroke selection, and movement coordination throughout the simulation. Renshaw et al.

(2022) emphasized that representative learning environments should promote exploration and functional movement variability instead of repetitive technical reproduction, thereby supporting greater adaptability during competitive performance.

The developed learning model further reflects the principles of Representative Learning Design, which emphasizes preserving the informational characteristics of actual competition during practice. Pinder et al. (2011) argued that representative practice strengthens perception–action coupling and facilitates the transfer of learning from practice to competition. Because the VR application realistically simulated badminton rallies and tactical situations, participants practiced not only stroke execution but also anticipation, tactical awareness, and contextual decision-making. Consequently, the developed learning model provided opportunities for learners to experience authentic badminton situations before participating in real competition.

Another important finding concerns learner engagement throughout the intervention. Immersive virtual environments encourage active participation by allowing learners to interact directly with realistic badminton scenarios while receiving immediate performance feedback. Stone et al. (2022) reported that extended reality technologies improve motor learning by creating highly interactive learning environments that closely resemble competitive situations. Likewise, Makransky & Petersen (2018) explained that immersive VR increases learners' sense of presence, cognitive engagement, and intrinsic motivation, thereby improving learning effectiveness. These characteristics are particularly important in badminton because successful performance depends on rapid perception, attention, and decision-making under time constraints.

Compared with previous technology-assisted badminton instruction, the present study provides a broader pedagogical contribution by integrating Game-Based Learning, Ecological Dynamics, Constraints-Led Approach, and Representative Learning Design into a single immersive learning model. Previous studies have generally emphasized technical improvement through wearable technologies or digital instructional media. In contrast, the proposed VR model simultaneously promotes technical performance, tactical awareness, perception–action coupling, contextual decision-making, and adaptive movement behavior within representative badminton match scenarios. This integrated approach offers a more authentic learning experience that better reflects the complexity of actual badminton competition and extends the application of immersive technology beyond isolated technical training.

The findings of this study also have important implications for sport education in higher education institutions. The developed VR learning model can complement conventional badminton instruction by providing students with repeated opportunities to experience representative game situations without requiring a complete competitive environment. Such an approach enables lecturers to design more student-centered learning experiences while facilitating the simultaneous development of technical skills, tactical understanding, and adaptive decision-making. Therefore, integrating immersive VR technology into badminton instruction represents a promising strategy for improving both learning quality and student engagement in practical sport courses.

Despite these promising findings, several limitations should be acknowledged. First, the study involved a relatively small sample of university students from a single institution, which may limit the generalizability of the findings. Second, the intervention evaluated only short-term learning outcomes and did not examine long-term retention or the transfer of learning to official badminton competitions. Future studies should involve larger and more diverse participant samples, compare athletes with different levels of expertise, and investigate the integration of artificial intelligence, motion tracking, and adaptive feedback systems to further optimize immersive badminton learning.

Comparison

To better illustrate the contribution of the proposed VR-based *Badminton Simulating In-Game Scenarios*, a comparison with previous badminton learning technologies is presented in Table 3. Previous studies have primarily focused on improving badminton performance through animated learning media, wearable technology, or modified equipment. Although these approaches have demonstrated positive effects on technical skill development, they generally provide limited opportunities for learners to experience realistic game situations and tactical decision-making.

In contrast, the present study integrates immersive Virtual Reality with representative in-game scenarios that simultaneously train technical execution, perception-action coupling, tactical awareness, and decision-making. Consequently, the developed learning model provides a more comprehensive badminton learning environment that better reflects real competitive conditions.

Table 4. Comparison with Previous Studies.

Study	Technology	Learning Focus	Main Contribution	Limitation
Sugiyanto et al. (2023)	Animated Video	Technical instruction	Improves understanding of badminton techniques	Passive learning environment
Lin et al. (2021)	Wearable Technology	Technical performance	Provides movement similarity feedback	Limited tactical interaction
Gazali et al. (2026)	Virtual Reality	Comparison of VR and conventional badminton learning	VR significantly increased engagement and enjoyment compared with conventional learning	Focused on engagement and enjoyment rather than performance outcomes
Present Study	Virtual Reality-Based Badminton Simulating In-Game Scenarios	Technical skills, tactical decision-making, perception-action coupling	Immersive representative learning environment with realistic match scenarios	Requires VR hardware availability

Compared with previous research, the present study contributes by integrating immersive virtual reality technology with representative learning principles to create realistic badminton match simulations. The developed model enables learners to practice technical skills while simultaneously improving tactical awareness and decision-making under game-like constraints. This integration extends previous badminton learning technologies beyond isolated technical practice and provides a more authentic learning experience suitable for university-level badminton instruction.

5. Conclusions

This study successfully developed and evaluated a Virtual Reality (VR)-based Badminton Simulating In-Game Scenarios learning model using the ADDIE development framework. The developed model was designed to create representative badminton learning experiences by integrating immersive virtual environments with realistic tactical game situations. Statistical analysis demonstrated significant improvements in both player performance scores ($p = 0.007$) and match-winning performance ($p = 0.002$), indicating that the proposed learning model effectively enhanced badminton skills among university students. These findings support the research objective of developing an effective VR-based badminton learning model while confirming the potential of immersive simulation for improving technical performance and tactical decision-making.

The findings also contribute to the growing body of knowledge regarding technology-enhanced sport education by demonstrating that representative virtual learning environments can provide meaningful practice opportunities beyond conventional skill drills. The integration of Virtual Reality with badminton-specific tactical scenarios offers an innovative instructional approach that promotes learner engagement, perception-action coupling, and contextual decision-making during practice. Despite these promising findings, several limitations should be acknowledged. The study involved a relatively small sample of university students from a single institution, limiting the generalizability of the findings. Furthermore, the intervention focused on short-term learning outcomes and did not examine long-term skill retention or transfer to actual competitive performance.

Future research should include larger and more diverse participant samples, compare different levels of player expertise, investigate long-term learning effects, and explore the integration of artificial intelligence, motion tracking, and adaptive feedback systems within immersive badminton training environments. Such developments may further improve the effectiveness and personalization of technology-supported badminton instruction.

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