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Article

Design and effectiveness of a physical education teaching platform using virtual reality technology and insights from biomechanics

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Abstract: To enhance the effectiveness of physical education and improve students' learning experiences, this work explores the design of a physical education teaching platform system based on Virtual Reality (VR) technology. First, a VR-supported physical education system is constructed and project-based learning and Science, Technology, Engineering, Arts, and Mathematics (STEAM) educational concepts are innovatively integrated into the design of the system's objectives and teaching content. The system's functionality and performance are tested across various VR devices. The results indicate that the devices consistently and effectively support the operation of the VR system, providing reliable technical support for physical education activities. Additionally, taking tennis teaching as an example, a comparative experiment was conducted on college students in the experimental group and the control group to assess the impact of the VR system on students' tennis skills and learning attitudes and to explore how VR affects biomechanical performance in physical activities such as tennis. The visual cues of the ball's trajectory and speed can influence a player's anticipatory muscle activation and movement initiation. Through repeated exposure to different ball flight patterns in VR, players can develop more accurate muscle recruitment strategies. The kinematic chain of movements in tennis, from the feet to the torso, arm, and racquet, can be analyzed and optimized with the help of VR. It allows players to visualize and correct any inefficiencies or incorrect biomechanical sequencing. The results show that after the intervention, the experimental group achieves an average score of 91.8 in tennis skills, compared to 83.8 in the control group, with a p-value of < 0.001. In terms of overall learning attitude, the experimental group has a mean score of 4.04, while the control group scores 3.22, with a p-value < 0.001. These findings demonstrate that, compared to traditional teaching methods, VR-based teaching more effectively improves students' tennis skills and learning attitudes. The results of this work provide theoretical support and practical guidance for the application of VR technology in physical education, contributing to the improvement of teaching quality and effectiveness.

Keywords: virtual reality technology; physical education; virtual teaching system; performance testing; biomechanics

1. Introduction

With the rapid advancement of information technology, the application of Virtual Reality (VR) technology in education has been gaining widespread attention. VR technology, with its immersive, interactive, and visual advantages, offers learners a more intuitive and vivid learning experience, breaking through the limitations of traditional teaching environments [1,2]. In physical education, VR technology can simulate real sports scenarios, allowing students to practice in a virtual environment, thereby enhancing learning outcomes. Simultaneously, the application of VR technology provides teachers with new tools and methods for teaching, helping to optimize the design and implementation of physical education [3–5]. However, research on the use of VR technology in physical education is still relatively limited, requiring further exploration and validation.

In modern educational theory, project-based learning and the Science, Technology, Engineering, Arts, and Mathematics (STEAM) educational concepts have been widely applied. These approaches emphasize the development of students' comprehensive abilities in problem-solving and the integration of interdisciplinary knowledge [6]. This teaching model is particularly suitable for skill acquisition in physical education, as students must not only master technical movements but also apply them in real-life situations and receive feedback. However, traditional physical education methods face certain limitations in terms of resources and time, making it difficult to provide students with sufficient personalized guidance [7,8]. VR technology can address these shortcomings by creating realistic simulation environments, enhancing students' learning experiences, and improving the efficiency of their skill acquisition [9,10]. Therefore, the design of physical education platforms that combine VR technology with project-based learning and STEAM educational concepts has become a key focus of current research.

This work designs and implements a physical education teaching platform based on VR technology, integrating project-based learning and STEAM educational concepts. It uses tennis instruction as a case study to explore the design and application effectiveness of the system. First, the work provides a detailed introduction to the VR-supported learning model and describes the design objectives and implementation process of the physical education system. Next, the system's technical specifications are validated through comprehensive functionality and performance tests across various VR devices. Subsequently, the effectiveness of the VR system is analyzed through comparative experiments between an experimental group and a control group. Ultimately, this work offers both theoretical and practical references for the application of VR technology in physical education.

The main contributions of this work are as follows:

First, the work designs and implements a VR-based physical education platform, combining project-based learning and STEAM educational concepts, offering new methods for innovative system design in physical education.

Second, the system's functionality and performance are thoroughly tested across multiple VR devices, confirming the system's stability and efficiency on different hardware platforms, and ensuring its feasibility for practical teaching applications.

Third, through comparative experiments between an experimental group and a control group, the work empirically demonstrates the significant effects of VR technology in enhancing students' tennis skills and learning attitudes. This work provides both theoretical support and practical guidance for the application of VR technology in physical education.

2. Related work

The application of Virtual Reality (VR) technology across various fields has garnered widespread attention and is gradually becoming a vital tool for innovative teaching. Wang et al. explored the monitoring and identification of fake news in virtual communities, virtual societies, and the metaverse. They offered forward-looking insights into fake news detection and information security, thereby providing theoretical support and new research directions for fake news detection in virtual cyberspace [11]. Harknett et al. used remote sensing technology to collect high-resolution images for creating digital outcrop models of complex geological sites and employed VR technology to simulate real-world field mapping. Their research demonstrated that immersive VR experiences could enhance learning outcomes in geosciences [12]. Fitria reviewed the extensive application of VR in education. They highlighted its potential in multiple disciplines such as biology, chemistry, geography, film, informatics, mathematics, and history by creating entirely new simulated environments that improved learning outcomes [13]. These studies provide a comprehensive perspective on the application of VR, showcasing its broad potential to enhance educational effectiveness.

In the realm of physical education, the application of VR technology has similarly attracted significant attention. Feng et al. investigated the integration of VR technology into physical education. They found that VR significantly boosted students' interest and enthusiasm for sports, although challenges remain, such as how different teaching steps and objectives might affect student engagement [14]. Xie pointed out that traditional physical education often failed to engage students, whereas modern technologies like intelligent visual tools, VR, and motion sensors offered new methods for recording and analyzing movement data. These technologies can improve the effectiveness of physical education [15]. Additionally, Hong et al. showed that in sports education, particularly in the training of Paralympic athletes, a VR-assisted convolutional neural network framework provided a real-time interactive environment that improved athletes' confidence and knowledge of sports. This framework had a higher signal-to-noise ratio, faster response times, and lower error rates compared to traditional methods, demonstrating superior real-time performance [16]. These studies further validate the potential of VR technology to enhance physical education, particularly in stimulating student interest and providing personalized training.

Despite the existing research on the application of VR technology in education and physical education, there remains a relative paucity of studies specifically focused on its application in physical education. Current literature primarily centers on technical implementation and preliminary effectiveness verification, lacking a systematic design framework and comprehensive evaluation of outcomes. Therefore, exploring the systematic design and application effectiveness of VR technology in physical education, especially when combined with project-based learning and STEAM educational concepts, holds significant academic value and practical relevance. This work builds on these existing studies, proposing a VR-integrated physical education platform and conducting a systematic analysis of its design and application effectiveness to address the gaps in current research and provide practical guidance.

3. Design of the VR-based physical education system

3.1. Analysis of the VR-supported learning model

Using tennis instruction within physical education as an example, this work designs a VR-based teaching system. The VR-supported learning model primarily consists of two components: interactive virtual environment learning and project-based instruction, as illustrated in **Figure 1** [17–19].

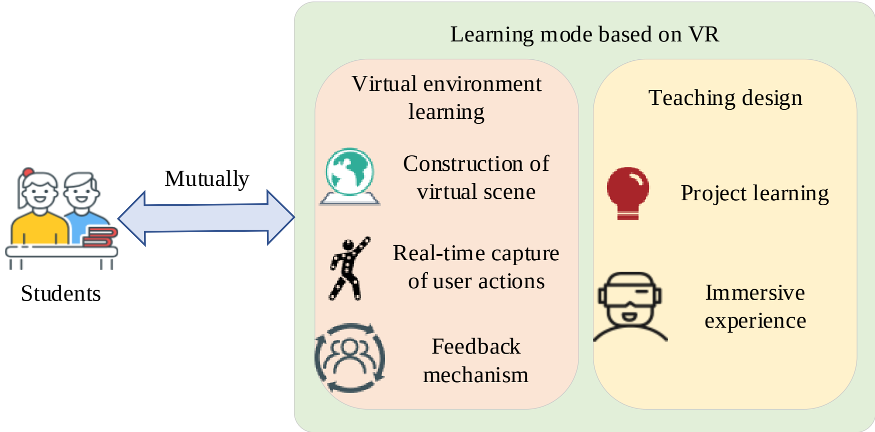

Figure 1. Learning model in virtual teaching.

In the learning model shown in **Figure 1**, interactive virtual environment learning involves the construction of a virtual tennis scenario, real-time motion capture of the user, and the implementation of a feedback mechanism. A highly realistic tennis environment is created using the Unity Three-Dimensional (3D) platform, allowing students to interact with virtual tennis rackets and courts through motion capture technology, providing an immersive tennis learning experience. The system utilizes real-time feedback to promptly correct errors in students' techniques, such as hitting and serving, helping them continuously refine their skills.

The instructional design primarily integrates project-based learning with immersive experiences. By setting a series of tennis-related project tasks, students are required to complete these tasks within the virtual environment, thereby enhancing their self-directed learning and problem-solving abilities. The VR environment not only offers students realistic scenarios but also fosters engagement and hands-on skills through contextual learning [20–22]. As students complete the tasks, they not only learn tennis techniques but also develop strategic thinking and decision-making skills, further deepening the learning outcomes.

3.2. Design goals of the physical education system

The VR-based physical education system integrates VR technology with tennis instruction, targeting primarily university students. The system allows students to immerse themselves in tennis learning and practice. It provides an immersive teaching experience that helps them more efficiently master tennis skills while also enhancing their enthusiasm and engagement in physical education [23,24]. **Figure 2** outlines the system's design goals and main teaching content.

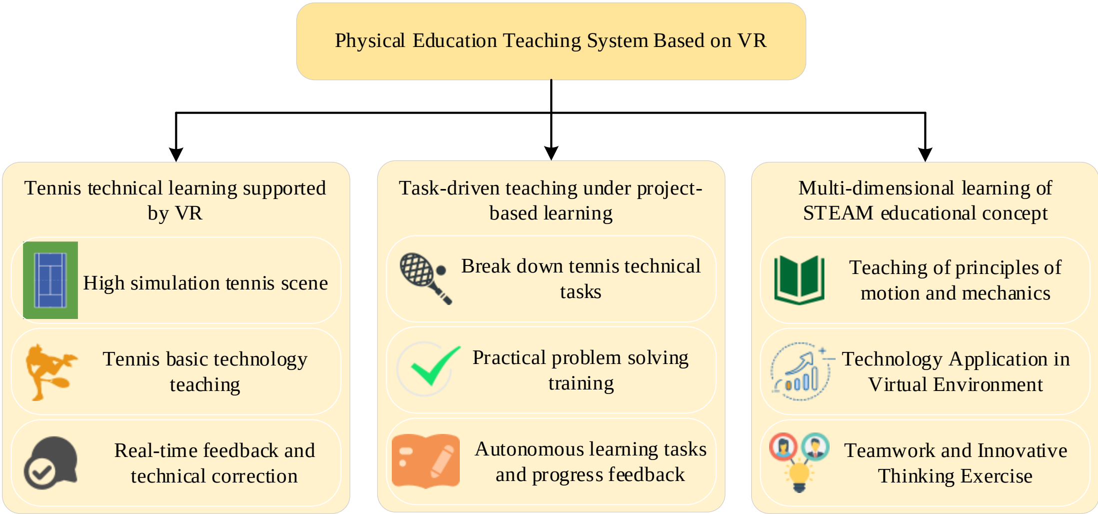

Figure 2. Educational goals and content of the system.

The instructional design of this system begins with tennis skill acquisition within a VR environment, gradually progressing to practice and application in simulated real-life tennis scenarios, followed by targeted feedback and improvement suggestions. This step-by-step approach allows students to progressively master fundamental tennis knowledge, rules, and techniques within an immersive virtual setting. The primary design goals of the system can be categorized into three main parts: First, through the application of VR technology, students can intuitively experience and learn tennis techniques in highly realistic virtual environments, improving their learning efficiency and mastery of tennis skills. Second, by employing a project-based learning model, students develop the ability to solve real-world problems while completing tennis-related tasks, simultaneously enhancing their motivation and interest in self-directed learning. Third, in addition to enhancing athletic skills in physical education courses, integrating the STEAM education approach can help students strengthen their multidisciplinary thinking and practical abilities through the comprehensive application of science, technology, engineering, and mathematics knowledge.

The theoretical framework of this work is built upon Project-Based Learning (PBL) and STEAM educational concepts. PBL emphasizes the promotion of students' active learning and collaborative skills through the resolution of practical problems. As students complete tasks within a VR environment, they not only hone their technical movements but also enhance their problem-solving abilities and team spirit [25]. Concurrently, STEAM education integrates interdisciplinary knowledge to cultivate students' innovative thinking and practical skills, enabling them to apply knowledge from science, technology, engineering, arts, and mathematics in practical operations [26]. VR systems not only offer immersive learning experiences that stimulate students' motivation to learn but also assist students in mastering skills through realistic scenario simulations and immediate feedback. This teaching platform, which integrates the STEAM concept, provides a new perspective for physical education, promotes the comprehensive development of students, and cultivates well-rounded talents who can meet the demands of future society.

3.3. Overall design and implementation process of the physical education system

The entire physical education system is composed of multiple functional modules, designed to provide students with an immersive tennis learning experience through VR technology. **Figure 3** presents the system architecture design.

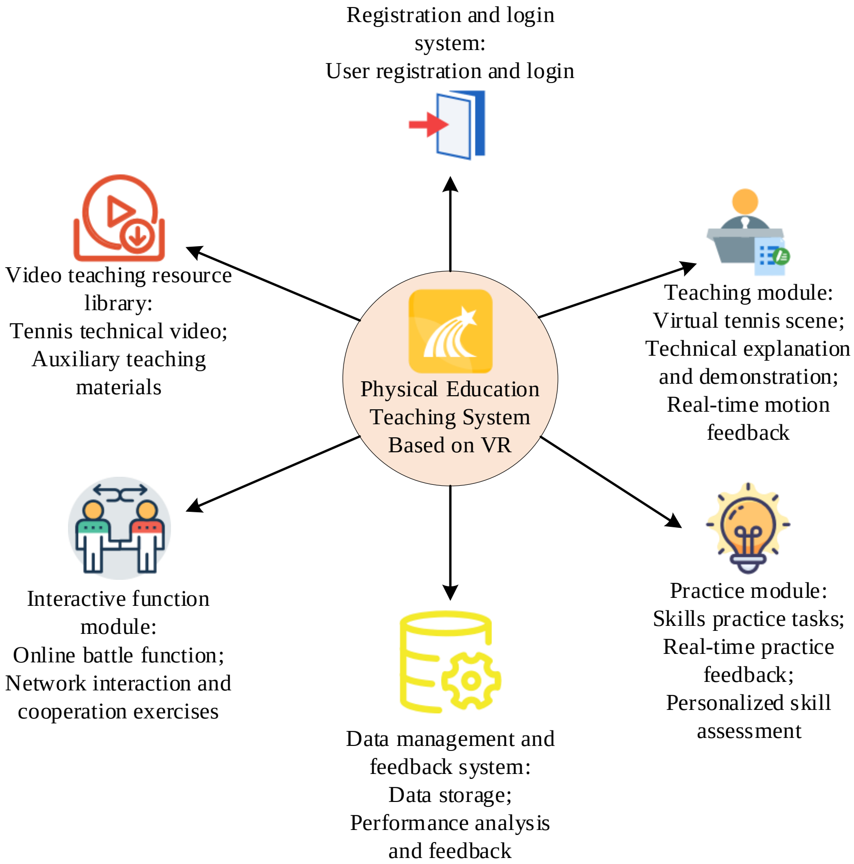

Figure 3. Overall system architecture.

First, the system includes registration and login functionalities. Once users successfully log in, they can access a personalized learning interface where they can select courses, engage in tennis skill learning, participate in virtual practice, and conduct assessments. The core of the system is divided into two main modules: (1) Teaching Module: This module features the display of virtual tennis scenes, explanations of tennis techniques, and interactive operations. Students can learn within the virtual environment, mastering basic tennis techniques and tactics. The module also provides real-time feedback to help students promptly correct their actions and enhance learning outcomes; (2) Practice Module: In this module, students complete predefined practice tasks and engage in practical tennis skill exercises within the virtual environment. Personalized feedback generated by the system further aids in improving their techniques.

The system architecture supports various hardware devices, such as VR headsets, controllers, and motion capture devices, to ensure accurate capture of students' movement data and integration with the learning process in the virtual environment. The backend of the system uses servers for data processing and management, with user login information, learning progress, and performance feedback being stored in a database in real time to ensure data security and integrity. The system also features a video teaching resource library, allowing users to access relevant instructional videos within the virtual learning environment to enhance the learning experience. Each practice and test result is recorded in the system for future reference and assessment. Additionally, the system includes interactive features, allowing students to practice individually in the VR environment and interact in real time with other users over the network. It also offers online competitive features, enabling students to engage in virtual matches with peers, increasing the fun and competitive aspect of learning. Through the project-based learning model, the system helps students not only learn tennis skills but also develop problem-solving abilities and team collaboration awareness.

This work innovatively integrates the STEAM education concept into the physical education platform based on VR technology. Specifically, the VR system facilitates interdisciplinary learning by designing a series of project tasks related to learning tennis skills. For example, when training a tennis serve, students need to apply the principle of parabolic motion (mathematics) in physics to optimize the trajectory of the serve. Meanwhile, they can understand the scientific principles of motion by simulating diverse environmental factors such as wind speed and direction. In addition, students can explore different racket designs (engineering) and enhance athletic performance through artistic expression. Such a design not only improves the students' motion skills but also encourages them to think and innovate in multiple fields such as technology, science, and art.

The implementation of the system is divided into two phases, as shown in **Figure 4**.

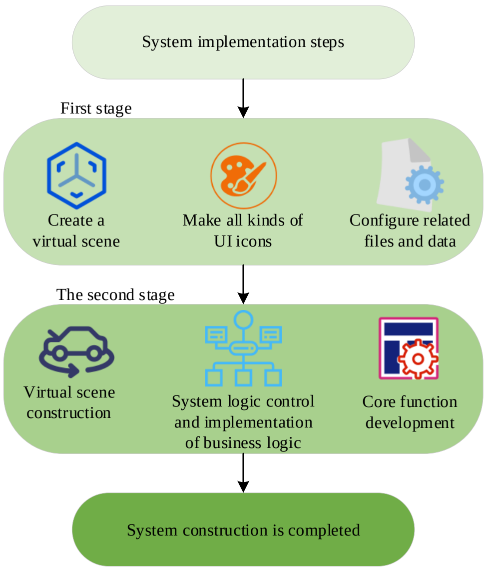

Figure 4. System implementation process.

Phase 1: Development Preparation. This phase involves preparing the necessary materials for the system. The main tasks include using 3D modeling tools, such as 3ds Max, to create detailed 3D models of the tennis court, racket, and character models within the virtual environment. This aims to ensure the high fidelity of the scene and objects. Additionally, image processing tools like Photoshop are used to create various User Interface (UI) icons, background textures, and lighting effects. Finally, files and data are configured according to system requirements to facilitate the smooth implementation of subsequent functionalities.

Phase 2: System Functionality Development. The core development of the system is based on the Unity 3D engine, a versatile platform widely used for game development and interactive 3D applications. Unity's advanced graphics rendering capabilities are utilized to create realistic virtual tennis environments, and its physics engine simulates authentic motion feedback. To achieve precise motion capture and interaction, the OptiTrack motion capture system is integrated, enabling real-time tracking of user movements and mapping them onto virtual characters. Additionally, the C# programming language is employed to code the interaction and business logic within Unity, ensuring the smoothness and responsiveness of user operations. For UI design, Adobe Photoshop and Illustrator are used to create intuitive and appealing interface elements such as icons, buttons, and backgrounds. These tools assist in designing a clear, easy-to-navigate UI, enhancing the user's learning experience. To support various hardware devices, the proposed system is designed to be compatible with mainstream VR headsets and controllers, such as the Oculus Quest 2 and HTC Vive Pro 2. Extensive testing is conducted through Unity's device adaptation features to ensure a consistent user experience across different hardware. Finally, for storing and processing user data, a MySQL database is utilized. The core function development of database design includes implementing registration and login features, real-time interaction and feedback, and specific tennis teaching functions. These are used to record users' learning progress, performance feedback, and test results in real-time while ensuring data security and integrity. The registration and login functions ensure the security and uniqueness of user data; The real-time interaction and feedback module provides immediate learning feedback and system assessment; The tennis teaching module encompasses the learning and evaluation of basic movements such as striking and swinging. Furthermore, the system integrates assessment and feedback functions to help students understand their learning progress and make improvements.

After the system development is complete, multi-device testing is conducted to ensure smooth operation across different hardware environments, including VR headsets and controllers, culminating in the release and application of the VR physical education system.

4. Performance verification of the physical education teaching system

4.1. Experimental design

To comprehensively evaluate the effectiveness and reliability of the VR-based physical education teaching system in terms of functionality and application, two experiments are designed: system performance evaluation and application effect testing.

(1) The system performance evaluation focuses on verifying the technical specifications and practical operation of the VR physical education teaching

system. This part includes hardware performance testing, software functionality testing, and user interaction experience evaluation. By testing the system's performance on different devices, key parameters such as response time, image processing capability, and data transfer rate are measured. This is to ensure the system can stably and efficiently support physical education teaching activities. Additionally, a user experience survey is conducted to assess the system's usability and user satisfaction, ensuring that the system design meets actual teaching needs and user expectations.

(2) The application effect testing aims to empirically verify the actual impact of the system on teaching effectiveness. Forty university students are invited to participate in the experiment, randomly divided into an experimental group and a control group. Students in the experimental group use the VR physical education teaching system for tennis instruction, while the control group employs traditional teaching methods. Before the experiment, all students undergo preliminary testing of their tennis skills and learning attitudes to establish baseline data. Tennis skills are assessed based on students' actual tennis abilities; the learning attitude questionnaire covers four dimensions: cognition of tennis, emotion, learning intention, and participation, with a Cronbach's α coefficient of 0.942, indicating good reliability. After a three-month teaching intervention, the same tests are administered to both the experimental and control groups to evaluate the impact of the teaching methods on learning attitudes and tennis skills.

In this work, to evaluate the application effects of VR technology in a physical education platform, a series of statistical analysis methods are employed to process and interpret the data. Initially, paired-sample t-tests are utilized to assess the changes in tennis skills and learning attitudes between the experimental and control groups before and after the intervention. This method is suitable for comparing data from the same group of subjects at different time points. Additionally, to compare the mean score differences between two independent groups (experimental and control), independent-sample t-tests are conducted, which helps to understand whether there are significant differences between the two groups. To address the issue of multiple comparisons, the Bonferroni correction method is applied to adjust the significance level, controlling the family-wise error rate. In other words, the risk of Type I error (incorrectly rejecting a true null hypothesis) is controlled in multiple hypothesis tests. Furthermore, the effect size (such as Cohen's d) is calculated to provide additional information about the practical significance of the intervention effects. This not only helps to understand the statistical significance of the differences between groups but also offers insight into the practical importance of these differences. All statistical analyses are performed under the assumptions of normal distribution of the data and homogeneity of variances. Before conducting t-tests, the normality of the data is verified using the Shapiro-Wilk test, and Levene's test is used to assess the homogeneity of variances. If the data violates these assumptions, non-parametric statistical methods, such as the Mann-Whitney U test or the Wilcoxon signed-rank test, are employed. Data analysis is conducted using SPSS 25.0 software to ensure the accuracy and reliability of the results. For all statistical tests, a significance level of 0.05 is adopted.

4.2. System performance testing

To ensure the system operates stably across various devices, testing is conducted using three representative VR hardware devices: Oculus Quest 2, HTC Vive Pro 2, and Meta Quest Pro. The testing involves a comprehensive evaluation of the system's response time, image processing capability, data transfer rate, system stability, usability, and user satisfaction. Usability and user satisfaction are assessed using a 5-point rating scale, with scores provided by volunteers who have participated in the system testing. **Figure 5** shows the results of the system performance evaluation across the three devices.

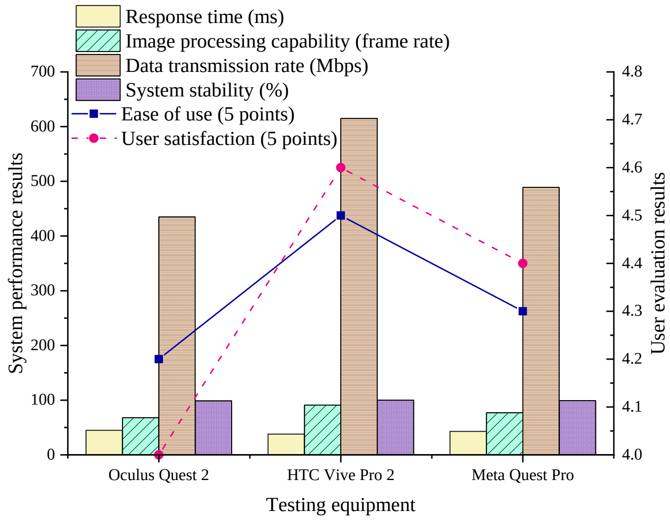

Figure 5. System performance testing results.

Figure 5 reveals that the three devices demonstrate good performance in terms of response time, image processing capability, data transfer rate, system stability, usability, and user satisfaction. Specifically, the HTC Vive Pro 2 shows the best performance in image processing capability (frame rate of 91) and system stability (99.99%), indicating its superior performance in high-load scenarios. The Oculus Quest 2 excels in response time (45ms), demonstrating its efficient response capability in real-time interactions. Overall, the HTC Vive Pro 2 stands out in comprehensive performance metrics. However, all devices can stably and effectively support the VR system's operation, providing reliable technical support for sports teaching activities. These results indicate that regardless of the device chosen, the system can achieve efficient and stable teaching experiences in a VR environment.

4.3. System application effect testing

4.3.1. Tennis skill testing

Table 1 shows the tennis skills of the experimental and control groups before the experiment.

Table 1. Analysis of tennis skills of both groups before the experiment.

Skill Dimension	Experimental Group		Control Group		*t*	*p*
	Mean (M)	**Standard Deviation (SD)**	**Mean (M)**	**Standard Deviation (SD)**		
One-Minute Ball Juggling	89.3	9.24	87.7	9.52	0.538	0.592
Serve Success Rate (%)	67.5	6.34	68.9	6.82	−0.672	0.503
Forehand Shot Success Rate (%)	75.2	8.91	73.8	8.57	0.846	0.400
One-Minute Rally Hits	43.4	5.18	42.7	5.12	0.372	0.711

Table 1 shows that before the experiment, the *p*-values for the tennis skills across all dimensions are greater than 0.05 for both the experimental and control groups. This indicates that there are no statistically significant differences in tennis skills between the two groups before the intervention, providing a balanced starting point for the subsequent teaching interventions.

After the intervention, professional tennis instructors evaluate the students' tennis skills. The assessment order for both groups is randomized. The total score is out of 70 points. They are 10 points each for forehand diagonal shots, backhand diagonal shots, forehand accuracy, and backhand accuracy, and 30 points for technical movements, including 10 points each for movement quality, footwork, and ball return effectiveness. **Figure 6** shows the tennis skill scores for both groups. Here, M represents the mean score, and SD denotes the standard deviation.

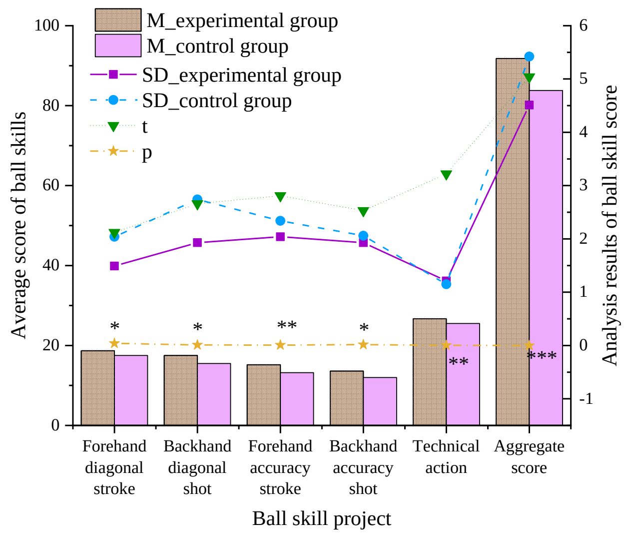

Figure 6. Analysis of tennis skill scores for both groups after the experiment.

Note: * denotes p significance at the 0.05 level, ** denotes p significance at the 0.01 level, and *** denotes p significance at the 0.001 level.

Figure 6 suggests that the experimental group performs significantly better than the control group in all assessment items. Specifically, the *p*-values for forehand diagonal shots, backhand diagonal shots, forehand accuracy, backhand accuracy, and technical movements are 0.04, 0.011, 0.008, 0.016, and 0.003, respectively, all less than 0.05, indicating statistical significance. Overall, the experimental group has an average score of 91.8, compared to 83.8 for the control group, with $p < 0.001$, showing an extremely significant difference. This indicates that the VR-based physical education teaching system significantly improves students' tennis skills, especially in terms of shot accuracy and overall technical movements, providing a clear advantage over traditional teaching methods.

4.3.2. Learning attitude test

Figure 7 displays the learning attitude test results for both groups before the experiment

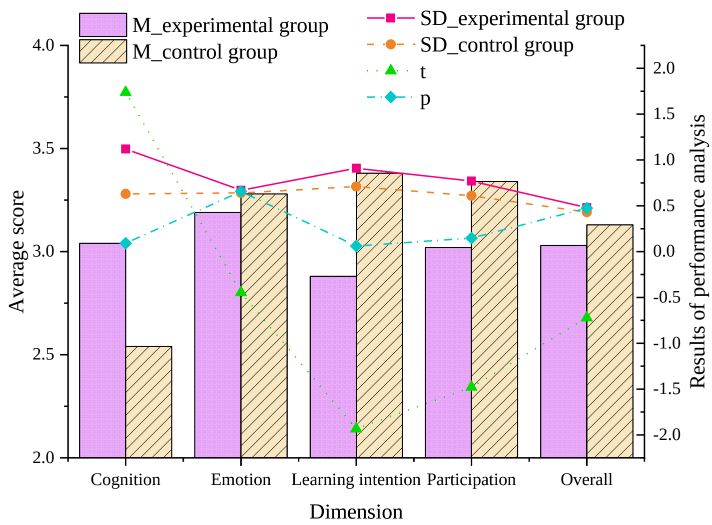

Figure 7. Analysis of learning attitudes for both groups before the experiment.

Figure 7 reveals that there are no significant differences between the experimental group and the control group in terms of cognition, emotion, learning intention, participation, and overall learning attitude. Specifically, the *p*-values for cognition, emotion, learning intention, participation, and overall learning attitude are all greater than 0.05, at 0.092, 0.657, 0.061, 0.147, and 0.475, respectively. This indicates that the learning attitudes of both groups are similar in all dimensions before the experiment, providing a balanced starting point for the subsequent experimental intervention.

Table 2 presents the comparison of learning attitude test results for both groups after the intervention.

Table 2 shows that the experimental group experiences significant improvements in all dimensions of learning attitude compared to before the intervention, whereas the control group shows no significant changes in any dimension. Specifically, the *p*-values for cognition, emotion, learning intention, participation, and overall learning attitude in the experimental group are all less than 0.001, indicating that these differences are statistically significant. In contrast, although the mean scores for all dimensions in the control group increase, the *p*-values are all greater than 0.05, suggesting that these changes are not statistically significant. This indicates that traditional teaching methods have limited effects on improving students' learning attitudes. Overall, the VR technology-supported intervention significantly enhances students' learning attitudes, whereas traditional teaching methods show relatively limited effectiveness in this regard.

Table 2. Intra-group comparison of learning attitude test results after the experiment.

Group	Dimension	Before Experiment		After Experiment		*t*	*p*
		Mean (M)	**Standard Deviation (SD)**	**Mean**	**Standard Deviation (SD)**		
Experimental Group	Cognition	3.04	1.12	4.23	0.29	−4.413	0.000***
	Emotion	3.19	0.67	3.83	0.3	−4.131	0.001***
	Learning Intention	2.88	0.91	4.09	0.63	−5.742	0.000***
	Participation	3.02	0.77	4.02	0.62	−4.101	0.001***
	Overall	3.03	0.48	4.04	0.33	−7.65	0.000***
Control Group	Cognition	2.54	0.63	2.69	0.49	−0.89	0.385
	Emotion	3.28	0.64	3.37	0.39	−0.849	0.406
	Learning Intention	3.38	0.71	3.46	0.6	−1.209	0.242
	Participation	3.34	0.61	3.36	0.55	−0.49	0.629
	Overall	3.13	0.43	3.22	0.26	−1.35	0.193

Note: *** indicates *p* significance at 0.001.

Figure 8 shows the inter-group comparison results between the experimental group and the control group.

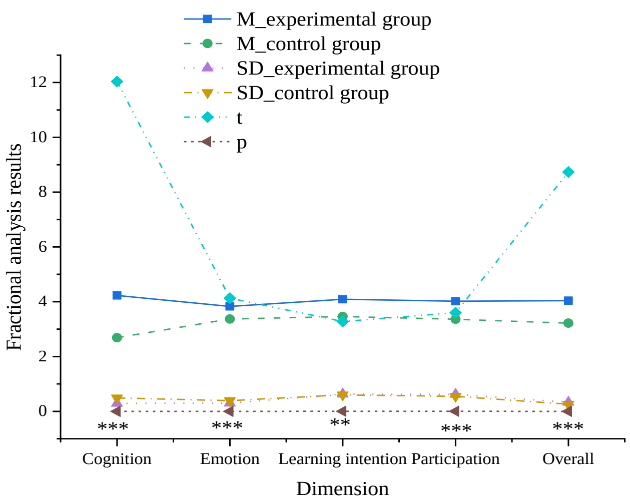

Figure 8. Analysis of students' learning attitudes after the experiment.

Note: * indicates p significance at 0.05, ** indicates p significance at 0.01, and *** indicates *p* significance at 0.001.

Figure 8 shows that the experimental group outperforms the control group in all dimensions, with *p*-values all less than 0.1. Specifically, in overall learning attitude, the experimental group's mean score is 4.04 compared to 3.22 for the control group, with $p < 0.001$. It indicates that the experimental group's overall learning attitude is significantly better than that of the control group. This result demonstrates that VR-based intervention teaching has a significant positive impact on the learning attitudes of students in the experimental group. Compared to traditional teaching methods, VR teaching is more effective in enhancing students' learning attitudes.

In summary, the VR technology-supported physical education system has shown significant advantages in improving students' tennis skills and learning attitudes. The experimental results indicate that the experimental group using the VR system significantly outperforms the control group in various indicators of tennis skills, particularly in ball accuracy and technical movements. Moreover, VR teaching significantly improves students' learning attitudes, including cognition, emotion, learning intention, and participation, with an overall learning attitude mean score significantly higher than that of the control group. These results suggest that VR technology not only effectively enhances sports skills but also significantly boosts students' motivation and attitudes, offering a stronger teaching effect and higher application value compared to traditional teaching methods.

5. Discussion

This work indicates that the experimental group of students using a VR technology-integrated STEAM concept-based physical education platform scores an average of 91.8 points in tennis skill tests; The control group of students using traditional teaching methods has an average score of 83.8, a statistically significant difference ($p < 0.001$). This illustrates that VR technology has a distinct advantage in improving students' tennis skills. Specifically, the experimental group scores significantly higher than the control group in technical movements such as forehand strokes, backhand strokes, and service success rates, which are key skills in tennis. Additionally, the experimental group's average score on a learning attitude questionnaire is 4.04, exceeding the control group's 3.22 ($p < 0.001$). This suggests that VR teaching remarkably enhances students' motivation and engagement, echoing the views of Chan et al. [27] and Jiang and Fryer. [28].

These findings have profound implications for sports practice. The application of VR technology may transform the role of teachers from traditional knowledge disseminators to facilitators and promoters of the learning process. As Marougkas et al. [29] proposed in their study, teachers could utilize data feedback provided by VR technology to offer more personalized guidance to students. Concurrently, curriculum design could place greater emphasis on students' active exploration and practical operation, rather than merely theoretical instruction. This student-centered teaching model helps to enhance students' interest and engagement, thereby improving teaching effectiveness.

Although this work primarily focuses on the short-term impact of VR technology in physical education, its potential for long-term application is equally noteworthy. In the long term, VR technology may positively affect students' learning motivation, and the depth, and durability of skill acquisition. In physical education, continuous skill practice and repeated practice are crucial for students' skill enhancement. VR technology provides a safe and repeatable practice environment, allowing students to engage in high-intensity training without the risk of injury. Furthermore, as technology advances and costs decrease, VR devices may become more widespread, enabling more schools and educational institutions to integrate VR technology into physical education courses. Future research can explore how to design and implement long-term VR teaching plans and how to assess the long-term impact of these plans on students' skill development and learning attitudes.

Future research needs to consider various factors to comprehensively evaluate the application effects of VR technology in physical education. They encompass how students with different skill levels adapt to VR environments and how to integrate VR technology with existing physical education courses and facilities. Additionally, researchers can explore the application of VR technology in different sports and how to design VR teaching content based on the characteristics of different sports. Long-term follow-up studies help understand the sustained impact of VR technology on students' skill acquisition and learning attitudes, as well as how to maximize the teaching effectiveness of VR technology by adjusting teaching strategies. Furthermore, considering costs and technological barriers, researchers can also explore how to make VR technology more widely available and accessible so that more students can benefit from it. Through these studies, a better understanding of the potential of VR technology in physical education can be achieved, offering a scientific basis for its application in practice.

6. Conclusion

This work proposes a VR-based physical education teaching platform system and demonstrates its effectiveness in improving the quality of sports education and students' learning attitudes through performance and application effect experiments. The following conclusions can be drawn: (1) Performance tests on three devices show that all devices can stably and effectively support the operation of the VR system, providing reliable technical support for sports teaching activities; (2) After the intervention, the experimental group's average score in overall tennis skills is 91.8, compared to 83.8 for the control group, with a p-value of < 0.001, indicating a highly significant difference. This result shows that the VR-based sports teaching system significantly improves students' tennis skills, particularly in terms of hitting accuracy and overall technical movements, offering a clear advantage over traditional teaching methods; (3) Post-intervention, the p-values for all dimensions of learning attitudes in the experimental group are less than 0.001, indicating significant differences in these dimensions. Conversely, while the control group shows some improvement in mean values, all p-values are greater than 0.05, indicating no significant differences. This suggests that VR-based intervention teaching can significantly enhance students' tennis skills and learning attitudes.

Despite the in-depth exploration of VR technology in sports education, this work has some limitations. First, the small sample size may limit the generalizability of the results. Second, not all VR devices and technology platforms are covered. Future research could extend to more devices for a comprehensive comparison. Future research can extend to a broader range of devices for comprehensive comparisons. Meanwhile, future work can explore the application of this VR system to other sports, such as basketball, soccer, or track and field, to assess its effectiveness and applicability in teaching different athletic skills. Additionally, researchers might consider how to integrate VR technology into a wider range of physical education courses, beyond the teaching of individual sports skills. This could include the development of interdisciplinary VR courses that combine physical education with knowledge from health, nutrition, or psychology domains to promote students' overall health and well-being. Through these extended applications, VR technology has the potential to revolutionize the landscape of physical education, providing students with richer, more interactive, and personalized learning experiences. Moreover, future studies should consider reducing the cost of VR technology and improving its accessibility so that a broader range of students can benefit from it. With ongoing research and innovation, VR technology is poised to become an indispensable part of future physical education, contributing to the cultivation of a healthy and active new generation.

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