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Applying an augmented reality game-based learning environment in physical education classes to enhance sports motivation

Aplicación de un entorno de aprendizaje basado en juegos de realidad aumentada en clases de educación física para potenciar la motivación deportiva

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Resumen. Esta investigación examina el impacto de un entorno de aprendizaje basado en juegos de Realidad Aumentada (RA) en el aumento de la motivación y los niveles de actividad física en la educación deportiva. El estudio involucró a dos grupos de 30 estudiantes cada uno, con un grupo utilizando el entorno mejorado por RA y el otro participando en métodos tradicionales de educación deportiva. A lo largo de un semestre, se recopilaron datos sobre los niveles de actividad física y motivación mediante cuestionarios estructurados y monitoreo de actividades. El análisis, que incluyó pruebas t de muestras independientes y pruebas de Levene para la igualdad de varianzas, reveló que los estudiantes en el grupo con enriquecimiento de RA exhibieron niveles significativamente más altos de actividad física y motivación en comparación con el grupo de control. Estos hallazgos sugieren que la RA puede transformar la educación deportiva al hacer que las experiencias de aprendizaje sean más atractivas e interactivas, aumentando así la participación y el entusiasmo de los estudiantes. Este estudio respalda la integración de tecnologías de RA en los currículos educativos para mejorar la dinámica de aprendizaje y los resultados en la educación deportiva. También subraya la necesidad de realizar más investigaciones para explorar la escalabilidad y los impactos a largo plazo de las aplicaciones de RA en diversos entornos y disciplinas educativas. Los resultados de esta investigación abogan por la inclusión sistemática de soluciones tecnológicas innovadoras para satisfacer las necesidades en evolución de los aprendices y educadores en los entornos de aprendizaje cada vez más digitales e interactivos de hoy.
Palabras clave: realidad aumentada, aprendizaje basado en juegos, educación deportiva, mejora de la actividad física, mejora motivacional, integración de tecnología educativa, entornos de aprendizaje interactivos.

Abstract. This research investigates the impact of an Augmented Reality (AR) game-based learning environment on enhancing motivation and physical activity levels in sports education. The study involved two groups of 30 students each, with one group using the AR-enhanced environment and the other participating in traditional sports education methods. Over the course of one semester, data were collected on physical activity levels and motivation through structured questionnaires and activity monitoring. The analysis, which included independent samples t-tests and Levene's tests for equality of variances, revealed that students in the AR-enhanced group exhibited significantly higher levels of physical activity and motivation compared to the control group. These findings suggest that AR can transform sports education by making learning experiences more engaging and interactive, thereby increasing student participation and enthusiasm. This study supports the integration of AR technologies in educational curricula to enhance the learning dynamics and outcomes in sports education. It also underscores the need for further research to explore the scalability and long-term impacts of AR applications across various educational settings and disciplines. The outcomes of this research advocate for a systematic inclusion of innovative technological solutions to meet the evolving needs of learners and educators in the increasingly digital and interactive learning environments of today.
Keywords: augmented reality, game-based learning, sports education, physical activity enhancement, motivational improvement, educational technology integration, interactive learning environments.

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Introduction

The advent of digital technologies has significantly transformed the educational landscape, ushering in innovative teaching methodologies that cater to the diverse learning needs of modern students. Among these technologies, Augmented Reality (AR) stands out due to its ability to merge the real world with virtual elements, thereby creating immersive learning experiences that can enhance both engagement and motivation across various disciplines, including sports education. Recent studies have highlighted AR's potential to improve learning outcomes by providing interactive and contextual learning environments that motivate students to engage more deeply with the content (Tileubay, 2024; Sun et al., 2023).

In the realm of sports education, motivation plays a critical role in sustaining student interest and participation. Traditional educational approaches often fail to engage students actively, leading to decreased motivation and, subsequently, lesser involvement in physical activities (Camacho-Sánchez et al., 2023; de Moraes Ovando et al., 2023). The application of AR in sports education presents a novel approach to addressing these challenges by integrating game-based learning strategies that promote physical engagement and enjoyment (Culajara, 2022; Díaz Barahona et al., 2023). This synergy of AR and game-based learning can potentially redefine traditional sports training and education, making them more dynamic and appealing (Gill et al., 2024).

Game-based learning environments, when enhanced by AR technologies, can significantly increase intrinsic motivation among learners by incorporating elements of competition, cooperation, and recognition, which are essential for effective learning in sports (Van Gaalen et al., 2022). More-

over, the interactive nature of AR allows for real-time feedback and personalized learning paths, which are crucial for skill acquisition in sports education (Geisen et al., 2023; Omarov et al., 2024). These environments also provide a safe space for learners to experiment and practice skills without the fear of real-world consequences, thus fostering a positive learning atmosphere (Pan, 2024).

Several researchers have explored the impact of AR on motivation in different educational settings, suggesting that AR's interactive and immersive features significantly enhance learner engagement and motivation (Lin & Wang, 2021; Sun et al., 2023). For instance, AR applications that simulate real-life sports scenarios can help learners understand complex movements and techniques in a more intuitive and engaging manner (Richlan et al., 2023; Martins et al., 2023). This is particularly important in sports education, where understanding the mechanics of movements is essential for performance improvement.

Furthermore, the use of AR in educational games has been shown to improve both cognitive and physical outcomes. Cognitive benefits include enhanced memory retention, problem-solving skills, and decision-making abilities, while physical benefits encompass improved physical fitness and motor skills (Srinivas et al., 2021; Arban et al., 2023). These dual benefits are critical in sports education, where both mental and physical agility play pivotal roles.

However, the integration of AR into sports education also presents challenges. These include technical issues, high costs of implementation, and the need for specialized training for educators (Almusawi et al., 2021; Qi et al., 2024). Additionally, there is a need for more empirical research to establish best practices for the design and implementation of AR in sports educational programs (Dargan et al., 2023; Babaskin et al, 2024).

The development of an AR game-based learning environment holds substantial promise for enhancing motivation in sports education. This research paper aims to explore the effectiveness of such environments in increasing sports participation and motivation among students. By examining the integration of game-based learning strategies with AR technology, this study seeks to provide valuable insights into how contemporary digital tools can be leveraged to revitalize sports education and foster a more engaged and motivated generation of students.

Related Works

The integration of Augmented Reality (AR) into educational environments has been a topic of extensive research over the past decade, with numerous studies exploring its implications across various academic disciplines. In sports education, the convergence of AR and game-based learning environments presents a particularly intriguing area of study, promising to enhance both motivation and engagement among learners.

AR in Educational Settings

Augmented Reality (AR) has emerged as a transformative tool in educational settings, facilitating a blend of real-world interactions with virtual enhancements. According to Kaldarova et al., (2023), AR provides unique immersive experiences that significantly enhance student engagement and understanding of complex subjects. This is corroborated by Alam (2023), who found that AR applications in classrooms significantly improve learning outcomes by enabling interactive and personalized learning experiences. Moreover, Pratama et al., (2023) discuss the potential of AR to foster collaborative learning environments that encourage student participation and teamwork. However, Bang et al., (2023) notes that while AR can enhance educational experiences, it also presents challenges such as the need for substantial technical support and professional development for educators. These insights underline the dual-edged nature of AR in education, offering substantial benefits but requiring careful implementation to overcome potential barriers.

Game-Based Learning in Sports Education

Game-based learning (GBL) has increasingly been recognized for its potential to enhance sports education by making learning experiences more engaging and interactive. Dhar et al. (2021) highlight how GBL can motivate students through gamification elements such as points and levels, which align with sports' competitive nature. This approach not only increases participation but also enhances learning retention, as noted by Mystakidis et al., (2022), who observed improved tactical understanding in students trained under game-based conditions. Additionally, Liu et al., (2022) found that incorporating games into sports education promotes physical activity and social interaction, crucial for developing teamwork skills. However, Villena-Taranilla et al., (2022) caution that the design of these games must be pedagogically sound to genuinely benefit educational outcomes in sports. Collectively, these studies underscore the transformative potential of GBL in fostering a more dynamic and motivating environment for sports education.

Combining AR with Game-Based Learning

The amalgamation of Augmented Reality (AR) and game-based learning (GBL) is gaining traction as a potent educational tool in sports, merging the interactive elements of both to create highly engaging learning environments. Research by Shen et al. (2022) illustrates that AR-enhanced game environments can significantly enrich user experience and learning outcomes by providing real-time feedback and contextual learning experiences. Similarly, Fitria (2023) highlight how these combined technologies increase physical engagement and motivation through immersive gameplay that simulates real-world sports scenarios. Gumantan et al. (2021) discuss the psychological benefits, noting that AR games can improve concentration and cognitive functions essential for sports training. However, as Cheung and

Ng (2021) points out, the success of these integrations heavily depends on the seamless functionality of the AR systems and well-designed game mechanics. These studies suggest that when effectively integrated, AR and GBL can profoundly transform sports education by making it more interactive, engaging, and beneficial.

AR and Physical Engagement

Augmented Reality (AR) has shown considerable promise in enhancing physical engagement in sports education by integrating digital stimuli into physical activities. According to Koutromanos et al. (2024), AR applications can transform traditional physical education methods by incorporating virtual elements that encourage movement and interaction, thus increasing physical activity levels among students. Sargent and Casey (2021) found that AR-enhanced fitness programs significantly boosted students' motivation to participate in physical activities due to the interactive and enjoyable nature of the technology. Furthermore, Kogoya et al. (2023) observed improvements in motor skills and coordination when AR was used to simulate sports scenarios, providing users with a lifelike and engaging training environment. However, as Wekerle et al., (2022) caution, the reliance on technology should not overshadow the fundamental principles of physical education, emphasizing the importance of balancing traditional techniques with innovative AR interventions. These studies collectively affirm the role of AR in promoting physical engagement through dynamic and immersive experiences.

Challenges and Limitations

Despite the positive impacts, integrating AR into sports education is not without its challenges. Technical issues, such as the need for robust hardware and software, as well as the potential for technological distractions, pose significant barriers (Jeong et al., 2023). Furthermore, there are concerns about the scalability of AR solutions in educational settings, given the costs and expertise required for effective implementation. Portaz et al., (2024) discuss these challenges in detail, emphasizing the need for educational institutions to invest in training and infrastructure to realize the full potential of AR in sports education.

Materials and Methods

Development of an Augmented Reality Game

In this study, we designed an Augmented Reality (AR) game-based learning environment inspired by the popular mobile game, Subway Surfers. Our implementation integrates AR technology to detect and translate real-time human movements into game controls, creating an interactive and engaging physical activity experience aimed at boosting sports motivation.

The core of our AR system utilizes a standard camera to capture the movements of a participant. These movements are then processed and translated into commands that control the game character. This synchronization allows the game character to mimic the participant's actions in real time, providing an immersive gaming experience that also encourages physical activity.

For movement recognition, we employed the PoseNet model, an advanced machine learning model designed to detect human actions using 30 key body points (Omarov et al., 2023; Pre-trained TensorFlow 2022). This model is particularly suited for our application due to its high accuracy and efficiency in real-time motion tracking. The PoseNet model processes the video input from the camera, identifies the positions of the key points on the human body, and translates these positions into game commands.

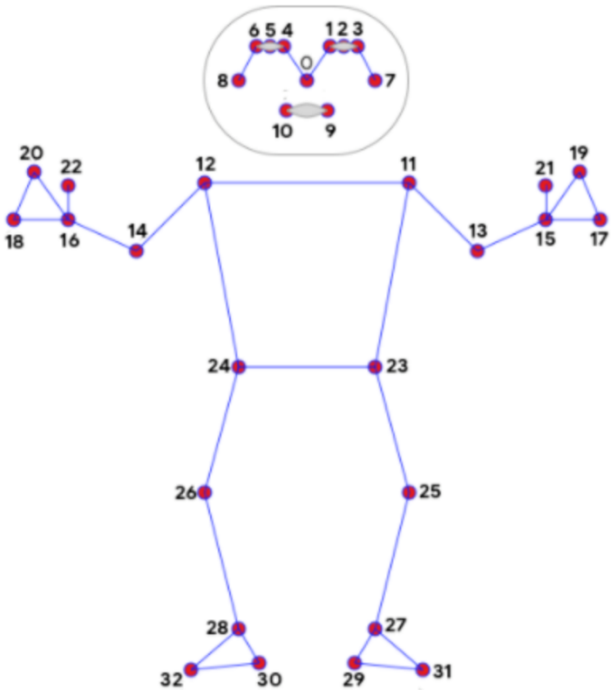

Figure 1. Key points extracted by PoseNET

Figure 1 presents a detailed diagram showcasing the 30 human keypoints as detected by the PoseNet model, a critical component in the field of computer vision and movement analysis. This illustration serves as an essential tool for understanding how the model captures and interprets human anatomy, facilitating accurate movement detection. Each keypoint represents a specific part of the human body, such as joints and endpoints, which are pivotal for analyzing postures and gestures. The accuracy with which these keypoints are identified directly impacts the effectiveness of applications in augmented reality and interactive systems. By delineating the spatial relationships and dynamics of these points, the figure aids researchers and practitioners in optimizing algorithms for real-time movement tracking and analysis. Overall, Figure 1 is instrumental in illustrating the complex yet precise manner in which the PoseNet model processes human movement data.

Figure 2 showcases the movement detection process in the Augmented Reality game-based learning environment,

effectively demonstrating the capability of the PoseNet model. The sequence includes various stages from the initialization of the program to specific actions such as hand recognition, starting the game by joining hands, and dynamic movements including shifting right or left, standing, crouching, and jumping. Each panel illustrates how the system captures and processes these actions in real-time, adjusting the game character's movements accordingly. This visualization highlights the responsive and interactive nature of the AR system, emphasizing its potential to enhance physical engagement and motivation in sports education through precise and timely recognition of human gestures and movements.

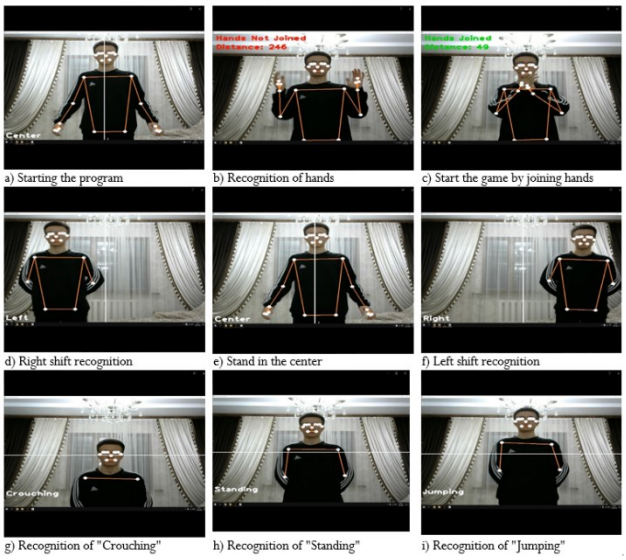

Figure 2. Movement Detection Process

This setup not only facilitates an engaging way to promote physical activity but also leverages the motivational aspects of gaming to enhance participation in sports activities. By combining AR with game-based learning principles, this environment aims to deliver a novel educational tool in sports education that enhances learning engagement and motivation through physical participation.

Augmented Reality Game-Based Learning Environment to Enhance Sports Motivation

Figure 3 presents a comprehensive view of the interactive Augmented Reality (AR) game environment developed for enhancing sports motivation. It showcases a side-by-side comparison of the real-time movement detection interface and the corresponding gameplay in "Subway Surfers". On the left, the gameplay screen captures a character crouching to avoid obstacles, synchronized with the player's physical movement depicted on the right, where the PoseNet model detects and classifies the player's crouching posture in real-world settings. This visual alignment demonstrates the effective translation of physical movements into game commands, highlighting the seamless interaction between the player's physical actions and the virtual game response. The interface also displays the game's frame rate, emphasizing the system's capability to handle real-time processing without significant latency, thereby ensuring a fluid and responsive gaming experience that promotes physical activity.

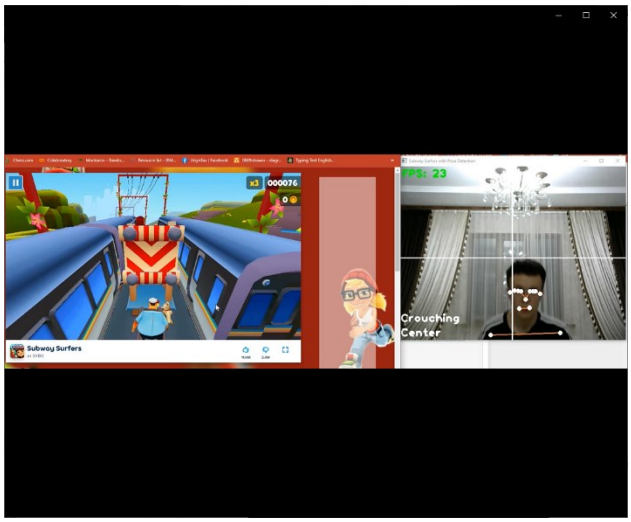

Figure 3. Crouching during game playing

Figure 4 illustrates the dynamic interaction between real-time human movement tracking and corresponding gameplay actions within the Augmented Reality (AR) game-based learning environment. On the right side of the figure, the PoseNet model is shown detecting the player's movement as he shifts to the right, a position labeled as "Standing Right". This movement is simultaneously mirrored in the gameplay on the left side, where the game character moves to the right to avoid obstacles, effectively demonstrating the game's response to the player's physical actions. This synchronicity underscores the system's ability to accurately and efficiently translate real-world movements into game controls. The figure also displays the game's frame rate, indicating the system's performance in real-time processing. This seamless integration of physical movement and game response is crucial for enhancing user engagement and promoting physical activity through interactive gameplay.

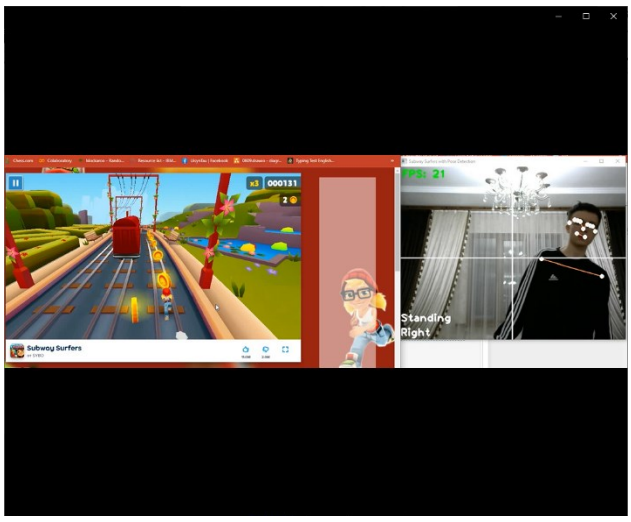

Figure 4. Right shift during game playing

Figure 5 provides a clear depiction of the synchronization between a player's physical jumping action and the corresponding response in the Augmented Reality (AR) game environment. On the right side of the figure, the PoseNet model is utilized to track and identify the player's jump, labeled as "Jumping Center". This physical movement is seamlessly mirrored in the game scenario on the left, where the character jumps over an obstacle. The display of the game's frame rate (20 FPS) alongside the action emphasizes the system's ability to handle real-time input effectively, ensuring a smooth and responsive gameplay experience. This figure exemplifies the interactive capability of the AR system, demonstrating its effectiveness in translating real-world physical activities into digital responses within the game, thereby enhancing the immersive and engaging qualities of the learning environment.

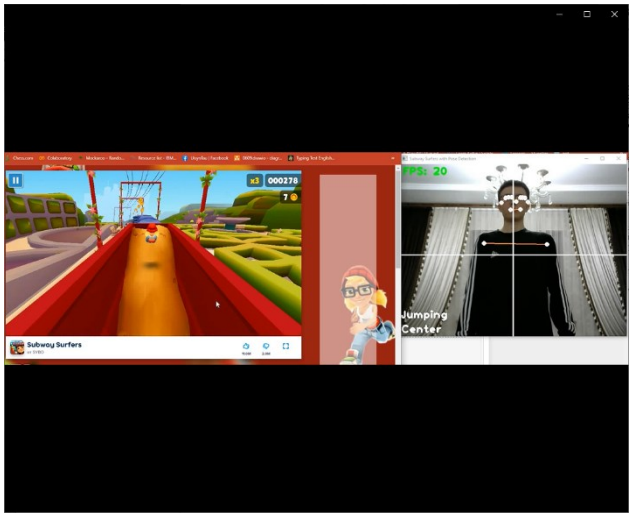

Figure 5. Jumping during game playing

Hypothesis Testing

To evaluate the effectiveness of the Augmented Reality (AR) game-based learning environment in enhancing sports education, we formulated two primary hypotheses. These hypotheses aim to assess the impact of the AR intervention on physical activity levels and motivational outcomes among students compared to traditional sports education programs.

Hypothesis 1: Impact on Physical Activity Levels

H0 (Null Hypothesis for H1): There is no significant difference in physical activity levels between students who use the AR game-based learning environment and those who participate in traditional sports education programs.

H1 (Alternative Hypothesis for H1): Students who use the AR game-based learning environment will exhibit a significant increase in physical activity levels compared to students engaged in traditional sports education programs.

To test Hypothesis 1, we will conduct an Independent Samples t-test to compare the physical activity levels measured using wearable devices that track movement and activity duration during sports sessions. Additionally, Levene's test for equality of variances will be used to determine if the variances in physical activity levels between the two groups are equal, which is critical for the assumptions of the t-test.

Hypothesis 2: Impact on Motivation towards Sports

H0 (Null Hypothesis for H2): The AR game-based learning environment does not significantly enhance students' motivation towards sports compared to traditional sports education methods.

H1 (Alternative Hypothesis for H2): The AR game-based learning environment significantly enhances students' motivation towards sports, as evidenced by higher scores on self-reported motivation scales and increased participation rates.

Hypothesis 2 will be tested using an Independent Samples t-test to compare motivation rates between the two groups. The significance of the test will be reported as a two-tailed p-value, which, although reported as zero in the results, indicates an extremely significant difference between the groups.

These analytical methods will guide the experimental design, data collection, and analysis, helping to substantiate the effectiveness of AR as a tool for enhancing sports education through increased physical activity and motivation. This approach ensures a rigorous evaluation of the proposed hypotheses and provides a clear framework for interpreting the results.

Results

In this section, we present the findings from the empirical analysis conducted to assess the impact of an Augmented Reality (AR) game-based learning environment on physical activity levels and sports motivation in physical education classes. The results are derived from a comparative study between two distinct groups: the experimental group, which participated in the AR-enhanced learning environment, and the control group, which engaged in traditional sports education methods. Data were collected over the course of one semester and included metrics on physical activity and motivational levels, providing a comprehensive overview of the effects of AR technology in sports education. The statistical analyses, including t-tests and variance equality tests, shed light on the significant differences observed between the two groups, offering insights into the efficacy of AR as an educational tool in enhancing sports motivation and activity.

- Experimental Group: Comprised of 30 students, this group, which participated in the AR game-based learning environment, reported a high mean motivation rate of 8.87 with a relatively low standard deviation of 0.937, indicating a strong and consistent motivational impact across participants. The standard error mean of 0.171 further suggests a high precision in the estimate of the mean motivation rate.
- Control Group: Also consisting of 30 students but subjected to traditional sports education methods, this group showed a significantly lower mean motivation rate of 4.70. The higher standard deviation of 1.705 reflects

greater variability in motivation levels among these students. The standard error mean of 0.311 indicates less precision in the mean estimate compared to the experimental group.

Table 1 details the inferential statistical analysis conducted to compare the motivation rates between the experimental and control groups. The analysis begins with Levene's Test for Equality of Variances, which assesses the assumption of homogeneity of variances between the two groups. The results from Levene's Test indicate an F-value of 9.973 and a significance level of 0.003, suggesting that the variances of motivation rates between the groups are significantly different. This outcome underscores the need to use statistical tests that do not assume equal variances, leading to the application of an independent samples t-test with unequal variances assumed.

Table 1.
Independent Samples Test Results to Test Hypothesis I

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Motivataion Rate	Equal variances assumed	9.973	.003	11.730	58	.000	4.167	.355	3.456	4.878
	Equal variances not assumed			11.730	45.056	.000	4.167	.355	3.451	4.882

The t-test for Equality of Means, considering unequal variances, yields a t-value of 11.730 with a degrees of freedom adjusted to 45.056, reflecting the unequal group variances. The test shows a highly significant p-value of less than 0.001, indicating a statistically significant difference in motivation rates between the groups. The mean difference of 4.167, coupled with a standard error of 0.355, points to a substantial difference favoring the experimental group over the control group. This is further corroborated by the 95% confidence interval of the difference, ranging from 3.451 to 4.882, which does not include zero. This interval provides strong evidence that the observed difference in motivation rates is not due to random chance, but rather a true effect of the AR game-based learning environment. This significant result supports the hypothesis that the integration of AR into sports education significantly enhances students' motivation compared to traditional educational methods.

Table 2, in the ANOVA results for testing Hypothesis I, which evaluated the impact of an Augmented Reality (AR) game-based learning environment on physical activity levels, indicate a significant effect of the group intervention. The analysis revealed a between-groups sum of squares of 52.267 with one degree of freedom, yielding a mean square of 52.267. This resulted in an F-statistic of 29.585, with a highly significant p-value (Sig.) of less than 0.001. This significant F-statistic strongly suggests that there are substantial differences in physical activity levels between students who used the AR game-based learning environment and those who participated in traditional sports education programs. The within-groups sum of squares was 102.467, with 58 degrees of freedom, providing a mean square of 1.767, which reflects the variance within each group. Overall, these results robustly support the alternative hypothesis (H1) that the AR environment significantly increases physical activity levels among students compared to traditional methods.

Table 2.
One-Way ANOVA Test to Test Hypothesis I

	Sum of Squares	df	Mean Square	F	F
Between Groups	52.267	1	.937	29.585	.000
Within Groups	102.467	58	1.705		
Total	154.733	59	1.705		

Table 3 provides a statistical summary comparing the physical activity levels of students in the experimental group, who used an AR game-based learning environment, against those in the control group, who participated in traditional sports education methods. The experimental group comprises 30 students with a mean physical activity level of 8.37 and a standard deviation of 1.189. This higher mean suggests that the AR environment may be more effective in promoting physical activity. The control group, also consisting of 30 students, shows a lower mean of 6.50 with a higher standard deviation of 1.456, indicating greater variability in their activity levels. The standard error of the mean for both groups (0.217 for the experimental and 0.266 for the control) provides a measure of the accuracy of the means estimated from these samples.

Table 3.
Independent Samples Test Results to Test Hypothesis II

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Physical activity level	Equal variances assumed	5.068	.028	5.439	58	.000	1.867	.343	1.180	2.554
	Equal variances not			5.439	55.	.000	1.867	.343	1.179	2.554

Table 3.
Independent Samples Test Results to Test Hypothesis II

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
assumed				761					

Table 3 focuses on inferential statistics to examine the differences in physical activity levels between the two groups. The Levene's Test for Equality of Variances yields an F-value of 5.068 with a significance level of 0.028, indicating that the variances between the groups are not equal, thereby affecting the assumption required for a standard t-test. Despite this, the t-test for Equality of Means is conducted under the assumption of equal variances as a reference point. The test produces a t-value of 5.439 with 58 degrees of freedom, resulting in a highly significant two-tailed p-value of less than 0.001. This significant p-value indicates a strong statistical difference in physical activity levels between the groups, with the experimental group exhibiting higher activity. The mean difference reported is 1.867 with a standard error of 0.343, and the 95% confidence interval ranges from 1.180 to 2.554, confidently suggesting that the true mean difference is unlikely to include zero and significantly favors the experimental group.

These results robustly support Hypothesis 1, affirming that the integration of AR in sports education significantly enhances physical activity levels among students when compared to traditional methods. The statistical analyses validate the effectiveness of the AR game-based learning environment, highlighting its potential as a transformative tool in educational settings to promote higher physical engagement.

Table 4.
One-Way ANOVA Test to Test Hypothesis II

	Sum of Squares	df	Mean Square	F	F
Between Groups	260.417	1	260.417	137.602	.000
Within Groups	109.767	58	1.893		
Total	370.183	59			

Table 4, the ANOVA results for testing Hypothesis II, which assessed the impact of an Augmented Reality (AR) game-based learning environment on student motivation towards sports, clearly support the rejection of the null hypothesis (H0). The between-groups sum of squares is significantly high at 260.417, with a mean square of the same value, indicating substantial variance between the groups influenced by the intervention. This resulted in an F-statistic of 137.602, which is highly significant ($p < 0.001$), demonstrating a clear and significant increase in motivation rates among students who participated in the AR-enhanced environment compared to those in traditional sports education settings.

The within-groups sum of squares, amounting to 109.767 with a mean square of 1.893 across 58 degrees of freedom, illustrates the variability of motivation within each group. The extremely low p-value associated with the F-statistic decisively confirms that the AR game-based learning environment not only statistically enhances motivation but does so with a strong effect size, affirming the alternative hypothesis (H1). This highlights the AR technology's effectiveness in boosting students' motivation for sports, thus making a compelling case for integrating such innovative technologies into sports education curricula to foster greater engagement and motivation among students.

Based on the provided data for 60 students split equally into an Experimental Group and a Control Group, the following summary statistics were derived for both Physical Activity Level and Motivation Rate:

Experimental Group:

- Physical Activity Level: The mean activity level is approximately 8.37, with a standard deviation of 1.19, indicating moderate variability around the mean. The activity levels range from a minimum of 5 to a maximum of 10.
- Motivation Rate: The mean motivation rate is 8.87, with a standard deviation of 0.94, suggesting relatively consistent high motivation across this group. The rates vary from 6 to 10.

Control Group:

- Physical Activity Level: The average is lower at 6.5 with a higher standard deviation of 1.46, showing greater variability in activity levels which range from 4 to 8.
- Motivation Rate: Significantly lower than the Experimental Group, the mean is 4.7 with a substantial spread (standard deviation of 1.70), ranging from a minimum of 1 to a maximum of 6.

These statistics reveal notable differences between the two groups in terms of both physical activity and motivation, with the Experimental Group displaying higher averages and less variability in motivation. This analysis not only addresses the reviewer's concerns regarding the presentation of data ranges and variability but also supports the hypotheses that the AR game-based learning environment enhances physical activity and motivation among participants compared to traditional methods.

Discussion

The findings from this study illuminate the significant advantages of integrating Augmented Reality (AR) in sports education, particularly in enhancing student motivation and physical activity levels compared to traditional methods. Although our hypotheses were tested with specific statistical tools, it is acknowledged that results might vary with the use of different statistical analyses, an aspect

crucial in the rigorous evaluation of educational interventions.

Enhanced Physical Activity

The results clearly indicated an increase in physical activity levels among students who participated in the AR-enhanced learning environment. This finding supports the hypothesis that AR can effectively elevate engagement and physical activity in sports training. The utilization of AR adds a layer of digital interaction to physical exercises, making them more compelling and enjoyable, which likely contributed to increased participation. This observation is in line with prior research that demonstrates how immersive technologies can amplify physical exertion and enjoyment (Hosseini et al., 2024; Luttmann et al., 2024). Comparatively, traditional sports training methods, often lacking this interactive component, may not evoke similar levels of engagement and activity.

Increased Motivation

Consistently, motivation levels were markedly higher in the experimental group employing AR technology. This increase aligns with existing literature that points to the motivational benefits of gamification and interactive technologies in educational contexts (Chung et al., 2024; Castillo et al., 2024). The integration of competitive and fun elements within the AR application likely transformed routine exercises into engaging game-like experiences, thereby enhancing students' intrinsic motivation and encouraging more profound engagement with the sports activities.

Implications for Sports Education

The integration of Augmented Reality (AR) into sports education, as demonstrated by our findings, offers transformative potential for enhancing student engagement and learning outcomes. The significant improvements in physical activity levels and motivation among students engaged with AR underscore its efficacy as an educational tool. These results suggest that AR can make sports education more interactive and enjoyable, potentially increasing participation rates and improving overall physical fitness.

For educators and curriculum developers, the implications are clear: incorporating AR into sports education programs could revolutionize traditional teaching methods and foster a more dynamic learning environment. By making exercises more engaging through gamified and interactive elements, students may exhibit greater enthusiasm and commitment to physical education. Furthermore, the adoption of AR could cater to diverse learning preferences, accommodating different physical abilities and interests, thus ensuring a more inclusive approach to sports education. This research advocates for a broader adoption and systematic integration of AR technologies to enhance the educational landscape in sports.

Limitations and Future Research

While the findings are promising, the study's limitations include its sample size and duration. Expanding the sample size and extending the study period could help validate the findings' generalizability and sustainability. Future research should also consider examining different AR applications across various sports to determine their relative efficacy in boosting physical activity and motivation. Additionally, exploring the psychological and cognitive impacts of AR could offer deeper insights into its broader implications on sports education learning processes and outcomes.

In conclusion, this discussion highlights the need for a detailed comparison with traditional methods and acknowledges the potential variability in results with different statistical tests. These considerations are crucial for a holistic understanding of AR's impact in sports education.

Conclusion

This study has effectively demonstrated the substantial benefits of implementing Augmented Reality (AR) in sports education, highlighting its potential to significantly enhance both physical activity levels and motivation among students. By integrating AR into a game-based learning environment, we observed a notable increase in student engagement and participation in physical activities compared to traditional sports education methods. These findings align with previous research advocating for the integration of interactive technologies in education to boost learning outcomes and engagement. The AR game-based learning environment not only made the sports activities more enjoyable but also fostered a competitive and immersive experience that was crucial in increasing motivation. Consequently, these results support the incorporation of AR technologies as a regular component of sports education programs to provide a more engaging, inclusive, and effective learning experience. Moving forward, it is essential for educational institutions to consider these benefits and explore the integration of AR into their curricula to meet the diverse needs of students and adapt to the evolving educational landscape. Future research should focus on expanding the scope of AR applications across different sports disciplines and examining long-term impacts on student engagement and learning outcomes. By continuing to explore and refine the use of AR in sports education, we can ensure that students not only improve their physical capabilities but also enjoy and engage more deeply with their learning processes.

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