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Augmented reality for badminton education: Development and evaluation of a learning application

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Abstract

Badminton instruction continues to face challenges in facilitating students' conceptual and visual-spatial understanding of court layout and game rules. Despite the widespread application of augmented reality (AR) in sports education, most studies have concentrated on motor skill development rather than conceptual learning. Therefore, this study developed and evaluated an augmented reality (AR) learning application to facilitate students' understanding of badminton court configurations and game regulations. The application was developed using a Research and Development (R&D) framework guided by the Multimedia Development Life Cycle (MDLC) model and initially evaluated with 20 Physical Education students. The application was evaluated through expert validation, usability testing, and pretest/posttest measures of conceptual understanding. The application received validity and practicality ratings of 86.25% and 88.0%, respectively. Students' mean scores improved from 69.20 to 83.75, with a statistically significant difference (p < .001), a large effect size (Cohen's d = 0.85), and a moderate N-Gain (0.47). These findings suggest that AR-based learning can effectively support students' conceptual and visual-spatial understanding of badminton court structures and game rules. This study contributes to the development of an AR-based learning application specifically designed to facilitate conceptual and visual-spatial learning in badminton education, while extending the pedagogical application of augmented reality beyond motor skill instruction toward concept-oriented learning. Nevertheless, the limited sample and lack of a control group may restrict the generalizability of the findings.

Keywords: Augmented reality, AR-based learning, badminton education, conceptual understanding, visual-spatial learning.

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Authors contribution: a – Preparing concepts; b – Formulating methods; c – Conducting research; d – Processing results; e – Interpretation and conclusions; f - Editing the final version.

INTRODUCTION

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Advances in digital technology have accelerated the integration of augmented reality (AR) into educational settings, including physical education and sport. AR enables the real-time integration of three-dimensional (3D) virtual objects into real-world environments, creating interactive, contextual, and immersive learning experiences (Cossich et al., 2023; Le Noury et al., 2022; Soltani & Morice, 2020). Previous studies have demonstrated that AR can enhance learning outcomes, cognitive engagement, and instructional effectiveness across various physical education contexts, including motor skill training, sports simulations, and movement analysis (Chang et al., 2020; Klochko et al., 2022; Silva et al., 2021). These developments suggest that AR has become an increasingly important pedagogical tool in physical education.

Despite the growing adoption of augmented reality in physical education, previous studies have primarily examined its effectiveness in improving motor skill acquisition (Chang et al., 2020), physical performance and training outcomes (Liang et al., 2023), students' motivation and engagement (Omarov et al., 2024), and simulation-based sports learning environments (Le Noury et al., 2022). In contrast, considerably less attention has been devoted to using AR for conceptual understanding and visual-spatial learning. This limitation is important because conceptual and visual-spatial knowledge provides the cognitive foundation for effective sports participation, enabling learners to understand game structures, court layouts, tactical positioning, movement patterns, and sport-specific regulations (Cheng et al., 2024). Such knowledge supports not only the acquisition of technical skills but also the development of tactical awareness, decision-making, and game performance by helping learners interpret spatial information and respond effectively to dynamic playing situations (González-Valero et al., 2024; Robles et al., 2020).

This gap is particularly evident in badminton education. Understanding court dimensions, service areas, boundary lines, player positions, and technical rules constitutes a fundamental component of badminton learning (Ortega-Toro et al., 2020; Valldecabres et al., 2020). Nevertheless, instructional materials related to court layout and game rules are still commonly delivered through verbal explanations, static images, and text-based resources, which often provide limited support for contextual and visual-spatial learning (Mezghanni et al., 2022). Although several studies have explored AR applications for badminton learning, these applications primarily focus on technical skill instruction and movement demonstrations rather than facilitating conceptual understanding of court structures and game regulations (Nabila & Sundari, 2024; Putra & Darmawiguna, 2017; Silva et al., 2021). Consequently, empirical evidence regarding the effectiveness of AR in supporting conceptual and visual-spatial learning in badminton remains limited, highlighting the need for further investigation in this area.

Understanding badminton court dimensions, service positions, boundary lines, and game rules requires more than memorizing factual information. Learners must develop accurate spatial representations of court structures and player positioning while integrating visual information with verbal explanations of game regulations (Ortega-Toro et al., 2020; Valldecabres et al., 2020). Research in sports pedagogy suggests that visual-spatial understanding plays a crucial role in tactical awareness, decision-making, and interpreting sport-specific situations (Ortega-Toro et al., 2020). Therefore, instructional approaches that support spatial representation, visual-verbal integration, and contextual interaction may be particularly beneficial for facilitating conceptual understanding in badminton learning.

These learning processes can be understood through the complementary perspectives of embodied cognition and multimedia learning theories. Embodied cognition proposes that knowledge is constructed through active interaction between the learner's body and the surrounding environment, allowing physical experiences to shape cognitive processes (Radu & Antle, 2017). In augmented reality (AR) environments, learners actively interact with virtual objects embedded within real-world contexts, facilitating the construction of accurate spatial representations and strengthening visual-spatial

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understanding through sensorimotor experiences (Bacca et al., 2014; Ibáñez & Delgado-Kloos, 2018). According to multimedia learning theory, learners achieve meaningful learning by integrating visual and verbal information through dual cognitive processing (Mayer, 2024). In badminton instruction, simultaneous presentation of three-dimensional court visualizations, interactive labels, and contextual explanations enables learners to connect spatial information with conceptual knowledge, improving their understanding of court layout, player positioning, and game rules. Consequently, AR integrates the principles of embodied cognition and multimedia learning by combining physical interaction with multimodal instructional content, providing a theoretically grounded approach to enhancing both conceptual and visual-spatial learning (Akçayır & Akçayır, 2017; Ibáñez & Delgado-Kloos, 2018). Nevertheless, empirical evidence demonstrating these integrated learning mechanisms in badminton education remains limited (Garzón et al., 2019).

Therefore, this study aims to develop and evaluate an AR-based learning application designed to support students' understanding of badminton court layout and game rules. The application integrates 3D visualization, marker-based tracking, and interactive simulations to create a more contextual, interactive, and immersive learning experience for physical education students. Given the limited research on AR-based conceptual and visual-spatial learning in badminton, this study offers three main contributions to the literature. First, it extends the application of augmented reality in physical education beyond motor skill training toward conceptual learning in badminton. Second, it focuses on developing learners' visual-spatial understanding of court structures and game regulations, an area that has received limited attention in previous AR research. Third, the study integrates embodied cognition and multimedia learning theories as the conceptual foundation for designing and evaluating the AR learning application, providing a theoretically informed approach to AR-based conceptual learning in sports education. Collectively, these contributions advance current knowledge on the educational use of AR and offer practical implications for developing innovative learning media in physical education.

METHOD

Research Design

An augmented reality (AR)-based learning application for badminton court layout and game rules was developed and evaluated through a Research and Development (R&D) methodology. The development followed the Multimedia Development Life Cycle (MDLC) model, which provides a systematic framework for designing, developing, and evaluating multimedia-based educational applications, including AR learning environments (Hadi et al., 2024; Nabila & Sundari, 2024). The developed application utilizes marker-based tracking technology to display three-dimensional (3D) virtual objects in real time through Android smartphones, enabling users to interact with visual representations of badminton court structures and regulations (Pangestu et al., 2020).

As illustrated in Figure 1, the MDLC framework comprises six sequential stages: concept, design, material collection, assembly, testing, and distribution. The concept stage involves analyzing users' needs and learning objectives. The design stage covers interface development, storyboarding, and creating 3D visualizations of the badminton court. Material collection involves gathering multimedia assets such as 3D models, marker images, icons, and audio files. During the assembly stage, the application was developed using Unity 3D and the Vuforia SDK to create an Android-based AR learning environment. The testing stage consisted of alpha testing and beta testing. Two media experts and two badminton content experts conducted alpha testing to evaluate the application's technical quality, visual design, interactivity, content accuracy, and instructional appropriateness. Beta testing involved 20 Physical Education students with prior badminton learning experience to assess usability,

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practicality, and preliminary learning effectiveness. The final stage, distribution, involved deploying the application as an APK for limited implementation.

Figure 1. Research Design Based on the Multimedia Development Life Cycle (MDLC)

Participants

The research participants consisted of 20 Physical Education students aged 18–25 who were actively participating in university-level badminton classes. A purposive sampling technique was applied to recruit participants who met the following eligibility criteria: (i) having at least two years' experience playing badminton, (ii) understanding the basic techniques and rules of badminton, and (iii) having no visual or neurological impairments. These criteria were established to ensure that participants possessed sufficient prior knowledge and experience in badminton, enabling them to evaluate the AR application and its learning content meaningfully. The number of participants was based on development research and pilot usability testing of technology-based learning media.

This study also involved two media experts and two subject matter experts for application validation. The media experts evaluated the application's visual design, interactivity, and usability, while the subject matter experts assessed the content's appropriateness and the accuracy of the badminton rules. All participants took part voluntarily and provided informed consent before the study. The research was conducted in accordance with educational research ethics, and participants' data confidentiality was maintained throughout the research process.

Instruments

Three instruments were employed in this study: (i) a Media and Material Validation Questionnaire, used for expert assessment; (ii) a User Practicality Questionnaire, administered to evaluate the application's practicality; and (iii) a Conceptual Understanding Test, used to assess students' learning outcomes. The Media and Material Validation Questionnaire evaluated media quality, interactivity, visualization, content appropriateness, and pedagogical suitability. Two media experts and two content experts completed the instrument using a five-point Likert scale ranging from 1 (highly inappropriate) to 5 (highly appropriate). The User Practicality Questionnaire measured students' perceptions of ease of use, display clarity, system responsiveness, and perceived usefulness based on usability indicators proposed by Revythi and Tselios (2019). Conceptual understanding was assessed using pretest and posttest items related to badminton court layout and game rules.

Before data collection, all instruments underwent content validity assessment through expert judgment. Aiken's V coefficients ranged between 0.87 and 0.91, supporting the adequacy of the instruments' content validity. Reliability was then assessed for the User Practicality Questionnaire and the Conceptual Understanding Test to examine their internal consistency. The results showed Cronbach's alpha coefficients of 0.92 and 0.85, respectively, exceeding the recommended threshold of 0.70 (Taber, 2018). Table 1 provides the validity and reliability results obtained for each instrument.

Table 1. Content Validity and Reliability of the Research Instruments

Instrument	Number of Items	Content Validity (Aiken's V)	Reliability (Cronbach's α)
Media and Material Validation Questionnaire	20	0.89	–
User Practicality Questionnaire	18	0.91	0.92
Conceptual Understanding Test	20	0.87	0.85

Note. Internal consistency reliability was calculated only for instruments administered to participants. The Media and Material Validation Questionnaire was evaluated through expert judgment using Aiken's V.

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Data Analysis

Data analysis involved descriptive and inferential procedures. Expert validation and user practicality results were summarized using mean scores and feasibility percentages. To examine changes in students' conceptual understanding, pretest and posttest scores were first assessed for normality using the Shapiro–Wilk test and subsequently compared using a paired-samples t-test. Cohen's d was used to estimate the effect size. At the same time, the normalized gain (N-gain) score was calculated to quantify the improvement in students' conceptual understanding following the use of the AR-based learning application. All statistical analyses were performed using IBM SPSS Statistics 26, with the significance level set at $\alpha = .05$.

RESULT

Results of the Augmented Reality Application Development

An AR-based learning application was successfully developed and implemented on Android devices using a marker-based tracking approach and the Multimedia Development Life Cycle (MDLC) framework. This application visualizes the badminton court layout and game rules in an interactive, contextual manner. As shown in Figure 2, the application's main interface displays a navigation menu comprising (i) Introduction to the badminton court, (ii) Simulation of game rules, and (iii) User guide. Once the user selects a menu item, the system activates the camera to detect markers and displays 3D objects in real time. Figure 3 shows a visualization of the badminton court's 3D objects that appear during the marker-scanning process. This visualization includes boundary lines, the service area, and the net position.

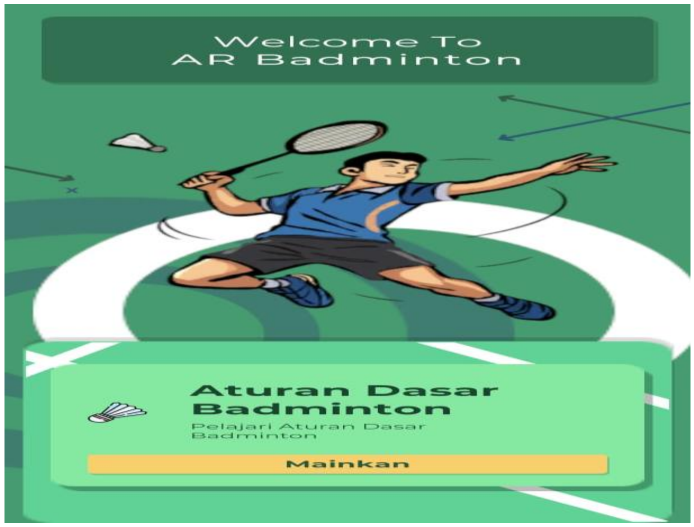

Figure 2. Main Interface of the AR-Based Badminton Learning Application

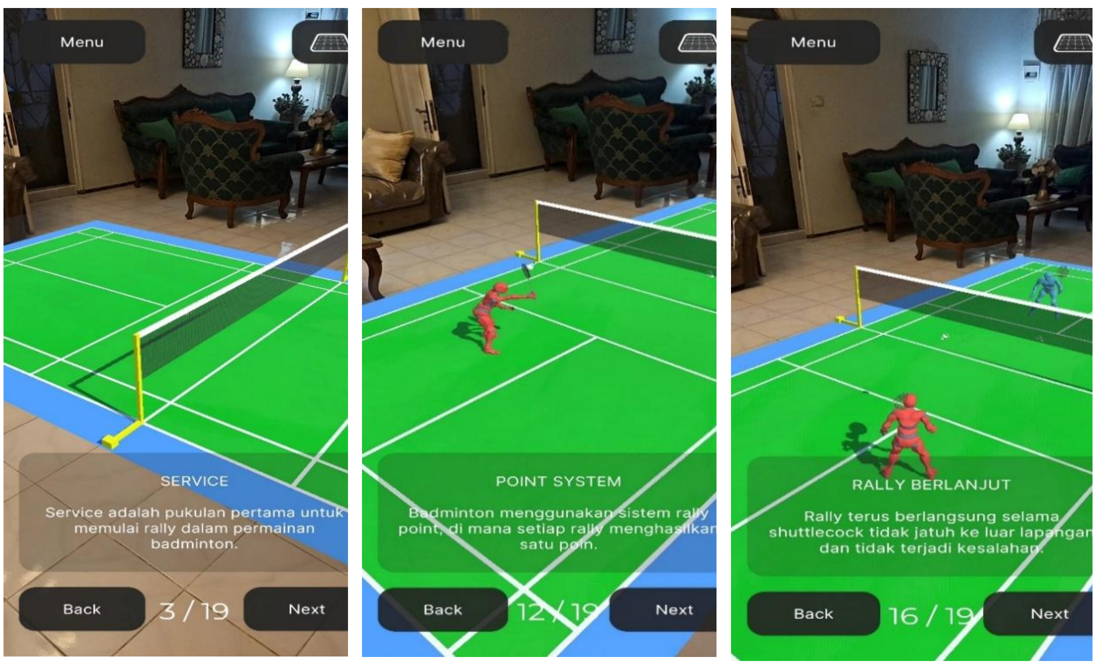

Figure 3. AR-Based 3D Visualization of the Badminton Court

Validity Results of the Application (Media and Content Experts)

The AR-based learning application was assessed for validity through an expert judgment process involving two groups of validators: media experts and content experts. This evaluation aimed to assess the application's suitability

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from pedagogical, content, and technical quality perspectives, as well as the interactivity of the developed system. Based on the data in Table 2, the analysis results indicate that the application falls into the valid category and is suitable for use as a physical education learning medium. The overall average score was 4.31, with a suitability rating of 86.25%, indicating that the application met quality standards in both content and technological design. Table 2 consistently shows that all assessment aspects fall within the valid category, reinforcing that the application has a satisfactory level of content and construct validity for use in a technology-based learning context.

Table 2. Expert Validation Results of the AR Application

Aspect	Mean	Percentage (%)
Accuracy of badminton rule content	4.32	86.4
Clarity of learning objectives	4.28	85.6
Accuracy of court visualization	4.35	87.0
Application interactivity	4.30	86.0
Overall mean	4.31	86.25

Note. Expert validation scores were measured using a five-point Likert scale.

Table 2 indicates that the accuracy of court visualization received the highest validation rating (*M* = 4.35; 87.0%). The accuracy of badminton rule content followed closely (*M* = 4.32; 86.4%), while application interactivity recorded a mean score of 4.30 (86.0%). Among the assessed aspects, clarity of the learning objectives received the lowest rating (*M* = 4.28; 85.6%). Nevertheless, all evaluated aspects exceeded the predetermined acceptance criteria.

Overall, the expert evaluation yielded a mean validity score of 4.31 (86.25%), indicating that the developed AR application satisfied the established feasibility criteria for content and media evaluation and was considered suitable for subsequent usability testing and field implementation.

Practicality of the Application

The application's practicality was determined from user feedback provided by Physical Education students during the limited trial. This evaluation aimed to measure usability, interface clarity, system responsiveness, and the application's perceived usefulness in supporting the learning process. As shown in Table 3, the analysis results indicate that the application falls into the ‘practical’ category with a high level of user acceptance. The overall average practicality score reached 4.40 (88.0%), indicating that the application is easy to use, responsive, and relevant to users’ learning needs. The findings in Table 3 consistently show that all measured aspects fall within the practical category, thereby reinforcing that the application has a satisfactory level of usability and can be effectively implemented in the context of technology-based physical education learning.

Table 3. User Practicality Evaluation of the AR Application

Aspect	Mean	Percentage (%)
Ease of use	4.42	88.4
Interface clarity	4.38	87.6
AR system performance	4.33	86.6
Perceived learning usefulness	4.47	89.4
Overall mean	4.40	88.0

Note. Scores were measured using a five-point Likert scale.

Table 3 indicates that perceived learning usefulness recorded the highest rating (M = 4.47; 89.4%), followed by ease of use (M = 4.42; 88.4%), interface clarity (M = 4.38; 87.6%), and AR system performance (M = 4.33; 86.6%). Although AR system performance received the lowest score among the evaluated aspects, all practicality indicators exceeded the predetermined acceptance criteria.

Overall, the developed AR application achieved a mean practicality score of 4.40 (88.0%), indicating that it satisfied the established practicality criteria and was considered suitable for implementation in the subsequent field evaluation.

Learning Effectiveness

The application’s effectiveness was assessed by examining changes in students’ conceptual understanding between the pretest and posttest assessments. The test measured students’ knowledge of badminton court

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dimensions, service areas, boundary lines, and game rules before and after using the application.

Table 4. Pretest and Posttest Scores with Statistical Comparisons

Variable	Pretest Mean ± *SD*	Posttest Mean ± *SD*	*t*	*p*	Cohen's d	N-Gain
Conceptual Understanding	69.20 ± 8.14	83.75 ± 7.26	6.12	< .001	0.85	0.47

Note. *t* = paired sample t-test; Cohen's *d* indicates effect size; N-Gain indicates normalized gain score.

Table 4 shows an increase in students' conceptual understanding after implementing the AR-based learning application. The mean score rose from 69.20 (*SD* = 8.14) at pretest to 83.75 (*SD* = 7.26) at posttest, corresponding to a gain of 14.55 points. The Shapiro–Wilk test confirmed the normality of the data (W = 0.96, p = .214), supporting the use of a paired-samples t-test. The analysis demonstrated a significant difference between the pretest and posttest scores (*t* = 6.12, p < .001), with a large effect size (Cohen's d = 0.85). The normalized gain was 0.47, indicating moderate improvement. As illustrated in Figure 4, posttest scores were generally higher than pretest scores across the participants.

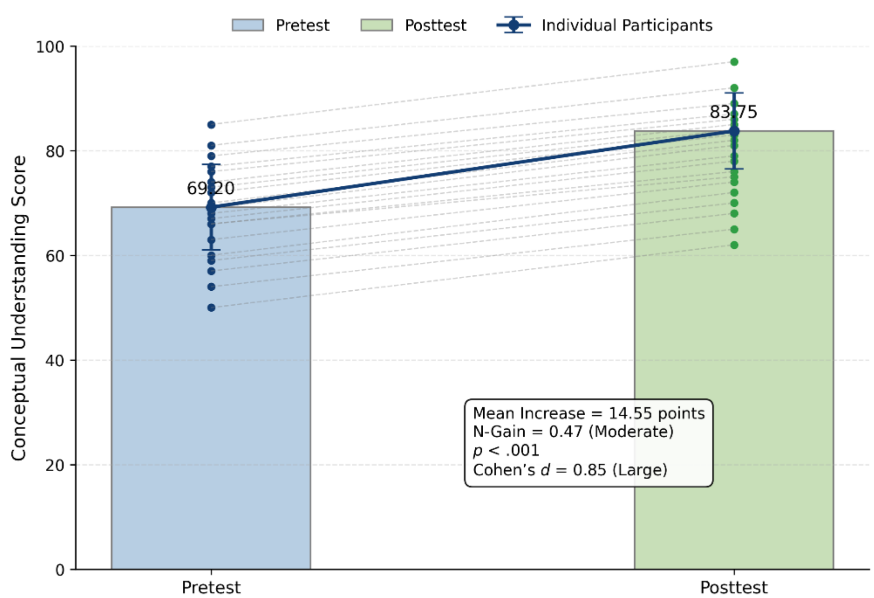

Figure 4. Pretest and Posttest Comparison of Students' Conceptual Understanding Scores

DISCUSSION

The study focused on developing and evaluating an augmented reality (AR)-based learning application designed to facilitate students' understanding of badminton court layout and game rules. The findings indicate that the application demonstrated high levels of validity, practicality, and learning effectiveness, suggesting that AR can serve as a promising medium for conceptual and visual-spatial learning in physical education.

The application's high validity indicates that integrating instructional content with AR technology was pedagogically appropriate. Previous studies have emphasized that the effectiveness of AR-based learning depends on the alignment among learning objectives, instructional content, and visual representations (Saidin et al., 2015; Soltani & Morice, 2020). In the present study, the application integrated three-dimensional visualizations of badminton court structures, marker-based interactions, and rule-based simulations, allowing learners to explore court dimensions, service areas, boundary lines, and game regulations in context. These features may explain the high validity scores, as they provide representations that are difficult to achieve through conventional text-based materials or static images. Earlier research has similarly demonstrated that three-dimensional visualizations delivered through AR can help learners comprehend complex spatial concepts while supporting the development of conceptual knowledge (Chang et al., 2020; Ibáñez & Delgado-Kloos, 2018). However, the educational effectiveness of AR depends not only on the quality of its visual features but also on learners' ability to engage meaningfully with virtual content in authentic learning settings (Radu & Antle, 2017). Therefore, continuous refinement of interaction design remains important to maximize learning benefits and minimize the risk of cognitive overload (Akçayır & Akçayır, 2017).

The practicality findings further suggest that users accepted the application well. Previous research has consistently identified perceived usefulness and ease of use as key determinants of learners' acceptance of

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educational technologies (Chen et al., 2025; Haedar & Marsasi, 2025). The positive practicality outcomes observed in this study indicate that participants perceived the application as relevant, accessible, and supportive of their learning needs. The integration of marker-based interaction and contextual rule simulations may have enhanced user engagement by allowing learners to explore badminton-related concepts rather than passively receiving information. These findings align with previous studies showing that AR can increase motivation, cognitive engagement, and participation through immersive, multimodal learning experiences (Liang et al., 2023; Omarov et al., 2024; Radianti et al., 2020). However, successful AR implementation still depends on technological conditions. Device capabilities, camera quality, and environmental factors have been reported as important determinants of AR performance and user experience (Garzón et al., 2020; Klochko et al., 2022). Consequently, technological stability should be considered a critical factor in the wider implementation of AR-based learning applications.

The improvement in students' conceptual understanding after using the application provides additional evidence of AR's educational value. The present findings support earlier evidence that AR-based learning can facilitate conceptual understanding, knowledge retention, and overall learning outcomes by allowing learners to engage interactively with digital representations in meaningful learning contexts (Cossich et al., 2023; Garzón et al., 2020; Ibáñez & Delgado-Kloos, 2018). From the perspective of embodied cognition theory, learning becomes more effective when cognitive processes are integrated with physical interaction and environmental context (Radu & Antle, 2017). Through marker-based interaction, learners could manipulate and explore virtual representations of badminton court elements in real-world settings, strengthening their conceptual and spatial understanding. Similarly, multimedia learning theory suggests that integrating visual and verbal information facilitates more effective cognitive processing (Mayer, 2024). The combination of 3D visualizations, interactive exploration, and contextual simulations incorporated into the application may therefore explain the observed improvements in conceptual understanding.

Although the learning outcomes improved, the N-Gain score remained within the moderate category. Several factors may explain this result. First, the duration of application use was relatively limited, reducing opportunities for repeated practice and reinforcement of conceptual knowledge. Second, the participants were Physical Education students who already possessed prior experience and basic knowledge of badminton, which may have reduced the magnitude of measurable learning gains. Third, the learning content focused primarily on conceptual understanding of court structures and game regulations, which may require repeated exposure and integration into broader instructional activities before substantial improvements can be achieved. These findings support previous research suggesting that AR effectiveness is influenced not only by technological features but also by instructional design quality, learning duration, and contextual implementation (Akçayır & Akçayır, 2017; Le Noury et al., 2022). Therefore, AR may be most effective when integrated within a broader blended-learning approach rather than being used as a stand-alone intervention.

The present study provides initial empirical evidence supporting the use of augmented reality (AR) for conceptual and visual-spatial learning in badminton education. Unlike many previous AR studies that have primarily focused on motor skill development and performance enhancement, this study examined how AR can facilitate learners' understanding of badminton court structures and game rules through interactive and contextual learning experiences. Furthermore, the study contributes to the literature by integrating embodied cognition and multimedia learning theories as the conceptual foundation for designing and evaluating the developed application. The findings contribute to the development of AR-based learning media specifically designed to support conceptual and visual-spatial learning in badminton

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education and provide practical implications for designing technology-enhanced instructional media within badminton learning environments.

Although the findings are encouraging, the study has several limitations worth considering. In particular, the small number of participants may limit how far the findings can be generalized to wider populations. In addition, the absence of a control group restricts the ability to compare the effectiveness of the AR application with other instructional approaches. Future research should consider experimental or quasi-experimental approaches with larger, more heterogeneous participant groups to strengthen the generalizability of the findings. Furthermore, additional variables such as learning motivation, engagement, self-efficacy, and long-term knowledge retention should be examined to provide a more comprehensive understanding of the educational impact of AR-based learning. Such investigations would further strengthen the evidence base regarding the role of AR in supporting conceptual and visual-spatial learning within physical education.

CONCLUSION

This study developed and evaluated an augmented reality (AR)-based learning application that effectively supports conceptual and visual-spatial learning in badminton instruction. The findings indicate that the application is valid, practical, and effective in improving students' understanding of badminton court layouts and game rules. These findings highlight the potential of AR-based learning media to enrich badminton instruction by supporting concept-oriented learning beyond the traditional emphasis on motor skill development. Future research should examine the application's effectiveness using experimental or quasi-experimental designs with larger, more diverse samples. Additional studies are also needed to investigate its impact on other learning outcomes, such as motivation, engagement, self-efficacy, and knowledge retention, and to explore its applicability in other physical education settings.

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