Vol. 7, No. 1, 2026, pp. 697-707
DOI: https://doi.org/10.29210/992640

Contents lists available at Elora Center

Lentera Negeri

Journal homepage: https://lentera.eloracenter.org/lentera

A quasi-experimental study of augmented reality athletics learning on motor skills and motivation in elementary students

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Article Info

Article history:
Received Jul 04th, 2026
Revised Jul 08th, 2026
Accepted Jul 10th, 2026

Keyword:
Augmented reality,
Athletics learning,
Fundamental movement skills,
Motivation,
Elementary school students,
Physical education

ABSTRACT

Fundamental movement skills (FMS) and learning motivation are essential for children's physical development and participation in physical activity. However, many elementary school students demonstrate low motor competence and limited engagement in physical education due to conventional instructional approaches that are often repetitive and less interactive. Augmented Reality (AR) technology has emerged as a promising tool to enhance learning experiences and increase student motivation. Therefore, this study aimed to examine the effects of AR-based athletics learning on FMS and learning motivation among elementary school students. A quasi-experimental pretest–posttest control group design was employed involving 60 students aged 9–11 years. Participants were assigned to either an experimental group receiving AR-based athletics instruction or a control group receiving conventional instruction. The intervention was conducted over eight weeks. FMS were assessed using the Test of Gross Motor Development-3 (TGMD-3), while learning motivation was measured using a validated questionnaire. Data were analyzed using paired-sample and independent-sample t-tests and Cohen's d effect size analysis. The results showed significant improvements in both FMS and motivation among students in the experimental group. FMS scores increased from 61.47 ± 6.28 to 78.53 ± 5.91, while motivation scores increased from 63.84 ± 5.74 to 82.15 ± 5.38 ($p < 0.001$). Large effect sizes were observed for FMS ($d = 1.42$) and motivation ($d = 1.58$). These findings indicate that AR-based athletics learning is an effective and innovative strategy for improving motor skills and learning motivation in physical education.

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Introduction

Fundamental movement skills (FMS) are widely recognized as the basic foundation of children's physical development because they support participation in sports, physical activity, and lifelong healthy movement behavior. FMS generally include locomotor skills such as running and jumping, object-control skills such as throwing and catching, and stability skills related to balance and coordination. During elementary school years, the development of these skills becomes highly important because childhood is considered a critical period for motor learning and neuromuscular adaptation (Robinson et al., 2015). Children who fail to develop adequate movement competence during this stage are more likely to experience difficulties in participating confidently in physical activities, which may negatively influence their physical fitness, social interaction, and long-term physical activity participation (Barnett et al., 2016). Recent evidence also indicates that inadequate motor competence in childhood is associated with increased sedentary behavior, obesity risk, and lower psychosocial well-being (Lubans et al., 2010; Roscoe et al., 2019). Therefore, improving FMS among elementary school students has become a major concern in physical education (PE) and child development research.

In elementary PE, athletics learning plays a significant role in supporting motor development because athletics activities involve various movement patterns closely related to FMS development, including running, jumping, throwing, and balancing activities. Through athletics instruction, children can improve movement coordination, agility, speed, and body control simultaneously. However, many schools still apply conventional instructional methods that rely mainly on verbal explanation and repetitive drills, which often reduce students' engagement and participation during PE lessons (Shaukat, 2023). Several recent studies have shown that elementary students frequently experience low motivation during PE classes due to monotonous teaching methods, lack of interactive learning media, and limited opportunities for active exploration (Liang et al., 2023). This condition becomes problematic because motivation is one of the most important psychological factors influencing children's willingness to participate in physical activity and persist in motor skill learning (Ryan & Deci, 2020).

Motivation in PE is strongly associated with enjoyment, perceived competence, and active engagement during learning activities. According to Self-Determination Theory (SDT), students are more intrinsically motivated when learning environments support autonomy, competence, and relatedness. In traditional athletics instruction, many students become passive participants because learning activities are less interactive and fail to stimulate curiosity or enjoyment. As a result, children with low motivation often demonstrate lower participation levels and weaker motor performance outcomes (Vasconcellos et al., 2019). This issue has encouraged educators and researchers to seek innovative instructional approaches capable of improving both movement competence and student motivation simultaneously.

The rapid development of educational technology has created new opportunities to improve PE learning quality through immersive and interactive digital tools. One of the most promising technologies currently used in educational settings is Augmented Reality (AR). AR is a technology that overlays digital objects, animations, or visual information onto real-world environments in real time, enabling users to interact simultaneously with physical and virtual elements (Bacca-Acosta et al., 2014). Unlike virtual reality, which fully immerses users in simulated environments, AR enhances real-world experiences without isolating learners from their surroundings. In educational contexts, AR has demonstrated considerable potential for increasing student engagement, visualization, attention, and experiential learning (Ibáñez & Delgado-Kloos, 2020). Because AR combines interactive visualization with real-time feedback, it may provide more meaningful movement learning experiences for elementary school students.

The integration of AR into athletics learning is particularly relevant because children generally respond positively to visual, playful, and technology-supported learning experiences. AR-based athletics learning can provide interactive movement demonstrations, movement tracking, visual guidance, and gamified learning activities that may improve students' understanding of movement patterns and increase learning enjoyment. In PE, AR applications may also facilitate observational learning by allowing students to repeatedly observe correct movement execution from different perspectives (Chen et al., 2017). Furthermore, real-time visual feedback can help students identify and correct movement errors more effectively, thereby supporting motor learning processes and improving FMS acquisition (Santos et al., 2014). These characteristics suggest that AR may enhance both cognitive understanding and physical performance simultaneously.

Recent studies have shown positive effects of AR implementation in educational and sports contexts. Research conducted by (Antonopoulos, 2024) found that AR-supported learning significantly improved students' engagement and motor performance during sports instruction. AR-based physical activity programs increased enjoyment and participation among elementary school students. A systematic review by Moreno-Guerrero et al. (2021) also concluded that AR technologies positively influence motivation, interaction, and learning effectiveness in PE settings. In addition, emphasized that immersive learning environments created through AR can stimulate active participation and improve students' learning experiences compared with traditional instructional approaches. These findings indicate that AR has strong potential as an innovative instructional medium in athletics learning.

Despite the growing body of literature regarding AR in education, several important limitations remain. Most previous studies have primarily focused on cognitive learning outcomes, technological usability, or student perceptions rather than examining motor development outcomes directly (Ibáñez & Delgado-Kloos, 2018). Research specifically investigating the effects of AR-based athletics learning on FMS among elementary school students is still limited. Furthermore, studies simultaneously examining both FMS and learning motivation within AR-supported PE instruction are relatively rare. Existing studies also frequently involve small samples, short intervention durations, or non-elementary educational settings, limiting the generalizability of findings. Therefore, there remains a clear research gap regarding the effectiveness of AR-based athletics learning for improving children's motor competence and motivation in elementary school contexts.

Another important issue relates to the practical implementation of innovative technologies in school-based PE programs. Teachers often face challenges such as limited instructional media, insufficient demonstration quality, and low student engagement during athletics learning. AR technology may offer practical solutions by enabling students to access interactive movement demonstrations repeatedly and independently. In addition, AR-based learning environments may create more enjoyable and student-centered instructional experiences, potentially increasing participation among children who are less interested in conventional PE instruction. Considering the increasing integration of digital technology in modern education, AR-based athletics learning also aligns with current educational transformation trends and students' digital learning preferences.

Despite the growing interest in augmented reality (AR) applications within physical education, empirical evidence examining the direct effects of AR-based athletics learning on elementary students' fundamental movement skills (FMS) and learning motivation remains limited. Previous studies have primarily emphasized cognitive engagement, technological usability, or student perceptions, while relatively few investigations have focused on measurable motor development outcomes in school-based athletics instruction. Furthermore, limited research has simultaneously examined both motor competence and motivational responses within AR-supported physical education contexts involving elementary-aged learners. This study contributes to the growing field of immersive physical education by integrating AR-assisted athletics instruction with process-oriented motor skill assessment in elementary school settings.

Therefore, this study employed a quasi-experimental pretest–posttest control group design to examine the effects of AR-based athletics learning on students' FMS and learning motivation. Fundamental movement skills were assessed using the Test of Gross Motor Development-3 (TGMD-3), while learning motivation was evaluated through a validated motivation questionnaire based on the Self-Determination Theory framework. Specifically, this study aimed to compare changes in motor skill performance and learning motivation between students receiving AR-supported athletics instruction and those receiving conventional athletics learning. It was hypothesized that AR-based athletics learning would produce significantly greater improvements in both FMS and motivation among elementary school students.

Method

Research Design

This study employed a quasi-experimental design using a pretest–posttest control group approach to investigate the effects of Augmented Reality (AR)-based athletics learning on fundamental movement skills (FMS) and learning motivation among elementary school students. The quasi-experimental approach was selected because the researchers used existing classroom groups without random assignment at the individual level, which is commonly applied in educational intervention studies involving school environments. The study involved two groups: an experimental group that received AR-based athletics instruction and a control group that participated in conventional athletics learning using traditional teacher-centered methods.

The intervention was conducted over eight weeks with two instructional sessions per week, resulting in a total of sixteen learning sessions. Each session lasted approximately 60 minutes and was integrated into the regular physical education (PE) curriculum. Both groups received the same athletics learning materials, including running, jumping, throwing, and balance-based movement activities. However, the instructional delivery differed between groups. The experimental group utilized AR-supported learning media, whereas the control group learned through verbal explanation, teacher demonstrations, and repetitive drills.

Participants

The participants consisted of elementary school students aged between 9 and 11 years enrolled in grades four and five at a public elementary school. A total of 60 students participated in the study, with 30 students assigned to the experimental group and 30 students assigned to the control group. The sample included both male and female students who regularly attended PE classes during the academic semester. An a priori statistical power analysis was conducted using G*Power 3.1 software to determine the minimum required sample size for detecting significant intervention effects. Assuming a medium-to-large effect size (f = 0.35), an alpha level of 0.05, and statistical power of 0.80 for repeated-measures comparisons, the minimum required sample size was estimated at 54 participants. Therefore, a total sample of 60 students (30 participants per group) was considered sufficient to achieve adequate statistical power and reduce the risk of Type II error.

The sampling technique used in this study was purposive cluster sampling because intact classroom groups were selected based on accessibility and school approval. Inclusion criteria included: 1) students actively participating in PE lessons; 2) students without physical disabilities or medical conditions affecting movement performance; and 3) students receiving parental consent to participate in the study. Exclusion criteria included: 1) students absent during more than 20% of intervention sessions; 2) students with injuries during the study period; and 3) incomplete assessment data. Prior to data collection, ethical approval was obtained from the institutional research ethics committee in accordance with educational research guidelines involving minors (AERA, 2020). Parents or guardians signed informed consent forms, while students provided verbal assent before participation. Confidentiality and anonymity of participant data were maintained throughout the research process.

Instruments and Measurements

Fundamental Movement Skills Assessment

Fundamental movement skills were measured using the Test of Gross Motor Development-3 (TGMD-3), which is one of the most widely validated instruments for assessing children's motor competence (Valentini et al., 2022). The TGMD-3 evaluates locomotor and ball skills through process-oriented movement criteria. In this study, the locomotor component included running, hopping, horizontal jumping, and skipping, while object-control skills included throwing, catching, kicking, and striking activities. Each skill was demonstrated by the assessor before testing. Students performed each movement twice, and performance was evaluated based on specific behavioral criteria outlined in the TGMD-3 manual. Scores from all movement components were summed to produce total FMS scores. Previous studies have demonstrated high reliability and validity of TGMD-3 in elementary-aged populations, with inter-rater reliability values exceeding 0.90 (Bolger et al., 2018).

In the present study, two trained assessors independently evaluated students' movement performances to ensure scoring consistency. Prior to data collection, inter-rater agreement training sessions were conducted using standardized TGMD-3 scoring guidelines. The inter-rater reliability coefficient obtained during pilot assessment was 0.92, indicating excellent scoring consistency. In addition, construct validity of the TGMD-3 has been consistently supported in elementary-aged populations, with reported validity coefficients ranging from 0.84 to 0.91 in previous validation studies.

Learning Motivation Questionnaire

Student motivation toward athletics learning was measured using an adapted Physical Activity Motivation Scale derived from the Self-Determination Theory framework. The questionnaire consisted of 20 items covering dimensions such as enjoyment, perceived competence, participation willingness, attention, and interest in athletics activities.

Responses were recorded using a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Prior to implementation, the questionnaire underwent content validation by three experts in physical education and educational psychology. Prior to implementation, the questionnaire underwent content validation by three experts in physical education and educational psychology. Construct validity testing conducted during pilot testing demonstrated acceptable factor loadings ranging from 0.71 to 0.86 across all questionnaire dimensions. Reliability analysis showed satisfactory internal consistency with a Cronbach's alpha coefficient of 0.88, indicating good reliability for use among elementary school students. Subscale reliability coefficients ranged from 0.81 to 0.87, confirming adequate consistency across motivational dimensions.

AR-Based Athletics Learning Intervention

The experimental group participated in AR-supported athletics learning activities designed specifically for elementary PE contexts. The AR application was developed to provide interactive movement demonstrations and visual feedback using tablet devices and smartphones. Students could observe animated athletic movements projected into real-world environments through the device camera. The application included demonstrations of running techniques, jumping mechanics, throwing movements, and balance exercises.

During learning sessions, students interacted directly with AR content while practicing movement tasks individually and in groups. Teachers guided students through movement activities while encouraging active exploration and repeated practice. Gamification elements such as point systems, visual rewards, and movement challenges were incorporated to increase engagement and enjoyment. Previous studies have shown that gamified AR learning environments can improve student participation and motor learning outcomes. Meanwhile, the control group received conventional athletics instruction consisting of verbal explanation, direct teacher demonstrations, and repetitive movement drills without digital assistance. Both groups followed identical learning objectives and instructional duration to maintain consistency across conditions.

Research Procedures

The research procedure consisted of four main stages: preparation, pretesting, intervention, and posttesting. during the preparation stage, researchers coordinated with PE teachers and school administrators regarding the implementation schedule and classroom organization. Teachers involved in the experimental group received training on operating the AR application and facilitating AR-assisted athletics learning activities. Instruments and assessment procedures were also pilot-tested prior to the main study. The pilot study involved 12 elementary school students who were not included in the main research sample. The pilot testing was conducted to evaluate instrument clarity, scoring procedures, AR application usability, and assessment consistency before the full intervention was implemented. In the pretest stage, all participants completed baseline FMS assessments and motivation questionnaires before the intervention began. The assessments were conducted in the school sports field and gymnasium under standardized conditions. Students were given instructions and demonstrations before performing each movement task.

The intervention stage lasted eight weeks. The experimental group participated in AR-based athletics instruction, while the control group followed conventional instruction. To reduce procedural bias, both groups were taught by the same PE teacher and completed activities within similar environmental conditions and lesson durations. Following the intervention period, posttests were conducted using the same procedures and instruments applied during pretesting. Researchers ensured that assessment conditions remained consistent between pretest and posttest sessions.

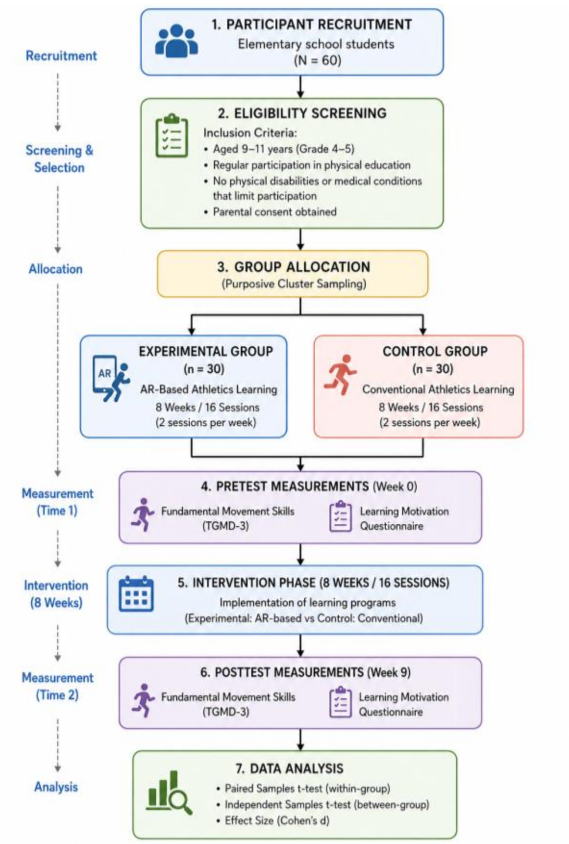

Figure 1. Research Design and Intervention Flowchart

Data Analysis

Data analysis was conducted using IBM SPSS Statistics version 26. Descriptive statistics including mean, standard deviation, minimum score, and maximum score were calculated to summarize participant characteristics and variable distributions. Before conducting inferential analysis, assumption testing was performed. Data normality was examined using the Shapiro–Wilk test because the sample size was below 100 participants (Ghasemi & Zahediasl, 2021). Homogeneity of variance between groups was tested using Levene's test.

To analyze within-group differences between pretest and posttest scores, paired sample t-tests were applied. Independent sample t-tests were used to compare posttest differences between the experimental and control groups. Additionally, effect size analysis using Cohen's d was conducted to determine the magnitude of intervention effects. Statistical significance was established at $p < 0.05$.

Results and Discussions

Participant Characteristics

This study involved 60 elementary school students who were divided equally into the experimental group and the control group. The experimental group received Augmented Reality (AR)-based athletics learning, while the control group participated in conventional athletics instruction. Participant demographic characteristics including age, gender distribution, height, and body weight were analyzed to ensure baseline equivalence between groups before the intervention.

The descriptive analysis indicated that both groups had relatively similar demographic characteristics. The mean age of participants in the experimental group was 10.23 ± 0.74 years, while the control group had a mean age of 10.17 ± 0.69 years. The distribution of male and female participants was also relatively balanced across groups. These findings suggest that both groups were homogeneous before the intervention program was conducted.

Table 1. Participant Characteristics

Variable	Experimental Group (n = 30)	Control Group (n = 30)
Age (years)	10.23 ± 0.74	10.17 ± 0.69
Male (n)	16	15
Female (n)	14	15
Height (cm)	138.42 ± 6.31	137.95 ± 5.88
Weight (kg)	34.16 ± 5.27	33.84 ± 5.11

To determine baseline equivalence between groups, independent sample t-tests were conducted on the pretest scores of fundamental movement skills (FMS) and motivation. The results demonstrated no statistically significant differences between groups at baseline ($p > 0.05$), indicating that the groups were comparable prior to the intervention.

Table 2. Baseline Comparison Between Groups

Variable	Experimental Group Mean ± SD	Control Group Mean ± SD	p-value
FMS Pretest Score	61.47 ± 6.28	60.92 ± 6.11	0.731
Motivation Pretest Score	63.84 ± 5.74	64.10 ± 5.61	0.842

Normality and Homogeneity Tests

Before conducting inferential statistical analysis, assumption testing was performed to examine data normality and homogeneity. The Shapiro–Wilk test was used to evaluate the normality of FMS and motivation data because the sample size was below 100 participants. Meanwhile, Levene's test was applied to assess homogeneity of variance between groups.

The results showed that all variables had significance values greater than 0.05, indicating that the data were normally distributed and homogeneous. Therefore, parametric statistical tests could be applied for further analysis.

Table 3. Results of Normality and Homogeneity Tests

Variable	Shapiro–Wilk p-value	Levene's Test p-value	Interpretation
FMS Pretest	0.214	0.387	Normal and Homogeneous
FMS Posttest	0.176	0.412	Normal and Homogeneous
Motivation Pretest	0.231	0.465	Normal and Homogeneous
Motivation Posttest	0.198	0.439	Normal and Homogeneous

Fundamental Movement Skills Results

The analysis of FMS scores demonstrated improvements in both groups after the intervention period. However, the experimental group showed greater improvement compared with the control group. The mean posttest FMS score in the experimental group increased substantially following participation in AR-based athletics learning.

Paired sample t-test results indicated a statistically significant improvement in FMS within the experimental group ($p < 0.001$). Although the control group also showed improvement, the magnitude of change was lower than that observed in the experimental group.

Table 4. Comparison of Fundamental Movement Skills Scores

Group	Pretest Mean ± SD	Posttest Mean ± SD	Mean Difference	p-value
Experimental	61.47 ± 6.28	78.53 ± 5.91	17.06	0.000
Control	60.92 ± 6.11	68.21 ± 6.37	7.29	0.012

The independent sample t-test conducted on posttest scores revealed significant differences between the experimental and control groups. Students who participated in AR-based athletics learning achieved higher FMS scores compared with students receiving conventional instruction.

Table 5. Independent Sample t-Test for FMS Posttest Scores

Variable	Experimental Group Mean ± SD	Control Group Mean ± SD	t-value	p-value
FMS Posttest	78.53 ± 5.91	68.21 ± 6.37	5.947	0.000

The percentage increase in FMS scores was also higher in the experimental group, indicating a stronger improvement effect resulting from AR-supported athletics learning.

Motivation Results

Student motivation toward athletics learning increased after the intervention in both groups. However, the increase was more pronounced in the experimental group that received AR-assisted instruction. Students exposed to AR-based learning demonstrated higher levels of enjoyment, participation willingness, and engagement during athletics activities.

The paired sample t-test results showed statistically significant increases in motivation scores within the experimental group ($p < 0.001$). The control group demonstrated a smaller but still statistically significant increase in motivation.

Table 6. Comparison of Motivation Scores

Group	Pretest Mean ± SD	Posttest Mean ± SD	Mean Difference	p-value
Experimental	63.84 ± 5.74	82.15 ± 5.38	18.31	0.000
Control	64.10 ± 5.61	70.22 ± 5.84	6.12	0.018

An independent sample t-test was subsequently conducted to compare posttest motivation scores between groups. The findings indicated significant differences favoring the experimental group.

Table 7. Independent Sample t-Test for Motivation Posttest Scores

Variable	Experimental Group Mean ± SD	Control Group Mean ± SD	t-value	p-value
Motivation Posttest	82.15 ± 5.38	70.22 ± 5.84	6.843	0.000

Effect Size Analysis

To determine the magnitude of the intervention effect, Cohen's d effect size analysis was performed. The results demonstrated that AR-based athletics learning produced a large effect on both FMS and learning motivation.

Table 8. Effect Size Analysis

Variable	Cohen's d	Effect Size Category
Fundamental Movement Skills	1.42	Large
Motivation	1.58	Large

The effect size findings indicate that the implementation of AR-based athletics learning had a substantial impact on improving students' movement competence and motivation compared with conventional instruction methods.

The findings of this study demonstrated that Augmented Reality (AR)-based athletics learning significantly improved both fundamental movement skills (FMS) and learning motivation among elementary school students compared with conventional athletics instruction. Students in the experimental group showed substantially greater improvements in locomotor and object-control skills, as reflected in the posttest TGMD-3 scores, while motivation scores also increased significantly after participation in AR-supported learning activities. These results indicate that integrating immersive digital technology into athletics instruction can positively influence children's motor development and psychological engagement during physical education (PE) learning.

One of the most important findings of this study is the significant improvement in FMS among students who participated in AR-based athletics learning. This result supports the theoretical perspective that motor learning becomes more effective when learners receive clear visual demonstrations, repeated practice opportunities, and immediate feedback during skill acquisition (Hebert & Coker, 2021; Muratori et al., 2013; Trabelsi et al., 2025). In the present study, the AR application provided interactive movement visualization that enabled students to observe and imitate movement patterns more accurately. Visual cues and animated demonstrations likely helped students understand proper movement execution, particularly during running, jumping, and throwing activities. According to observational learning theory, children learn motor behaviors more effectively when they can repeatedly observe modeled actions in engaging environments (Fryling et al., 2011; Han et al., 2022). Therefore, AR technology may strengthen the motor learning process by combining demonstration, interaction, and active movement practice simultaneously.

The large effect size observed in the FMS outcomes further suggests that AR-supported learning created meaningful improvements in movement competence beyond those achieved through traditional instruction. Conventional athletics learning often depends heavily on verbal instruction and repetitive drills, which may limit children's opportunities for interactive exploration and individualized feedback. In contrast, AR-based learning allows students to interact directly with movement content, making learning experiences more dynamic and student-centered. Similar findings were reported by (Utamayasa & Mardhika, 2024; Zhao et al., 2025), who found that immersive digital learning environments significantly improved movement accuracy and sports skill acquisition among school-aged children. Likewise, (Agung Pratama et al., 2022; Moreno-Guerrero et al., 2020) concluded that AR technology positively influences motor performance and participation in PE contexts because it enhances visual engagement and supports experiential learning processes.

In addition to improving FMS, this study also found that AR-based athletics learning significantly increased students' motivation toward PE activities. Students in the experimental group demonstrated higher levels of enjoyment, participation willingness, and engagement during learning sessions compared with the control group. This finding is consistent with Self-Determination Theory (SDT), which emphasizes that intrinsic motivation develops when learners experience enjoyment, competence, and autonomy during activities (Manninen et al., 2022). AR learning environments may satisfy these psychological needs by creating interactive and enjoyable learning experiences that encourage students to participate actively. The gamification features integrated into the AR application, including visual rewards and movement challenges, likely contributed to increased student interest and enthusiasm during athletics instruction.

The increase in motivation observed in this study is also consistent with previous research highlighting the positive relationship between educational technology and student engagement. (Hsiao, 2013; Lee & Huh, 2024; Stearne et al., 2025) reported that AR-based PE activities increased students' enjoyment and attention during physical activity sessions because the learning environment became more immersive and stimulating. Similarly, (Elamrani & Moughit, 2024; Hsiao, 2013) found that AR-supported sports instruction enhanced student participation and reduced boredom commonly experienced during conventional PE lessons. Elementary school students are generally highly responsive to visual and game-based learning experiences, and the AR intervention in this study appeared to align well with these developmental characteristics. Consequently, students became more enthusiastic and actively involved during athletics learning activities.

Another important aspect of the findings relates to the integration of digital technology within PE instruction. The increasing use of technology in educational settings has encouraged schools and teachers to adopt more innovative teaching approaches capable of improving both cognitive and physical learning outcomes. In this study, AR technology functioned not only as a visual aid but also as an interactive learning medium that promoted active participation and movement exploration. This finding supports the argument that technology-enhanced PE can create more meaningful learning experiences when properly integrated into instructional practice (Sargent & Calderón, 2021). Furthermore, the positive outcomes observed in this study suggest that AR has the potential to become an effective pedagogical tool for supporting physical literacy development among children.

Despite these positive findings, several limitations should be acknowledged. First, the study involved a relatively small sample size from a single elementary school, which may limit the generalizability of the findings to broader educational contexts. Future studies involving larger and more diverse populations are needed to confirm the effectiveness of AR-based athletics learning across different school settings. Second, the intervention duration was limited to eight weeks, meaning that the long-term effects of AR-supported learning on motor competence and motivation could not be fully examined. Longer intervention periods may provide deeper insights into whether improvements can be sustained over time. Third, motivation data were collected using self-reported questionnaires, which may be influenced by participant subjectivity or social desirability bias.

Technical factors also represent an important limitation. The implementation of AR learning depends on device availability, technological infrastructure, and teacher digital literacy. Some schools may face challenges related to limited access to mobile devices or internet connectivity, which could affect the practicality of large-scale AR integration in PE programs. Therefore, future research should explore cost-effective and accessible AR implementation strategies suitable for diverse educational environments.

Overall, the findings of this study provide important evidence that AR-based athletics learning can effectively improve both FMS and motivation among elementary school students. The integration of interactive digital technology into PE instruction may create more engaging and meaningful learning experiences while supporting children’s motor development. Future studies should continue exploring the long-term educational impact of AR in PE and investigate its effectiveness across broader physical literacy outcomes, including physical fitness, cognitive engagement, and social interaction.

Conclusions

This study demonstrated that Augmented Reality (AR)-based athletics learning produced significant improvements in both fundamental movement skills (FMS) and learning motivation among elementary school students compared with conventional athletics instruction. Students in the experimental group showed substantially greater gains in FMS scores (mean difference = 17.06 points) and motivation scores (mean difference = 18.31 points) following the eight-week intervention program. Large practical effects were also observed for FMS (Cohen’s d = 1.42) and learning motivation (Cohen’s d = 1.58), indicating that AR-supported athletics instruction had a substantial educational impact beyond statistical significance alone. The findings support the effectiveness of immersive and interactive digital learning environments in enhancing motor learning and student engagement during physical education. The integration of visual movement demonstrations, real-time feedback, and gamified instructional elements likely contributed to improved movement competence and increased intrinsic motivation among participants. The present study was supported by adequate statistical power (> 0.80) based on a priori power analysis, suggesting that the sample size was sufficient to detect medium-to-large intervention effects. Nevertheless, several limitations should be considered, including the use of intact classroom groups, implementation within a single school setting, and relatively short intervention duration. Future studies are encouraged to employ randomized controlled designs involving larger multi-school samples and longer intervention periods to examine long-term retention effects and broader educational applicability. Future research may also explore specific AR interaction features that most strongly influence motor learning outcomes and motivational engagement in physical education contexts.

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