The effect of Augmented Reality (AR) to enhance learning motivation, cognitive intelligence, and self-efficacy in Physical Education

Integración de la Realidad Aumentada (AR) para mejorar la motivación para el aprendizaje, la inteligencia cognitiva y la autoeficacia en la Educación Física

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Abstract

Introduction: Technological innovation in education, particularly Augmented Reality (AR), presents new opportunities to enhance motivation, cognitive abilities, and self-efficacy in physical education.
Objective: This study aimed to examine the effects of AR-based learning on students' learning motivation, cognitive intelligence, and self-efficacy in physical education.
Methodology: A true experimental design (Randomized Pretest-Posttest Control Group Design) was used. The population comprised 864 students of SMP Negeri 1 Purwokerto, with 96 students (M = 13.5 years, SD = 1.0) selected via simple random sampling. Instruments included the Physical Education Learning Motivation Questionnaire (PE-LMQ, Validity = 0.871, Reliability = 0.912), the Digit Span Test from WAIS/WISC (Validity = 0.911, Reliability = 0.943), and the Academic Self-Efficacy Scale (ASES, Validity = 0.889, Reliability = 0.907). Data were analyzed using normality, homogeneity, paired t-tests, and independent t-tests.
Discussion: Results showed that the data met assumptions for normality (sig = 0.421) and homogeneity (sig = 0.519). AR-based learning had a significant effect on all measured aspects (sig = 0.000), while the control group also showed effects (sig = 0.041). A significant difference between groups was found (sig = 0.001).
Conclusion: AR-based learning significantly improves motivation, cognitive intelligence, and self-efficacy in physical education, and outperforms traditional direct teaching models.

Keywords

Augmented reality; cognitive intelligence; learning media; learning motivation; self-efficacy.

Resumen

Introducción: La innovación tecnológica en la educación, en particular la Realidad Aumentada (RA), ofrece nuevas oportunidades para mejorar la motivación, las capacidades cognitivas y la autoeficacia en la educación física.
Objetivo: Este estudio tuvo como objetivo examinar los efectos del aprendizaje basado en RA sobre la motivación, la inteligencia cognitiva y la autoeficacia de los estudiantes en la educación física.
Metodología: Se utilizó un diseño experimental verdadero (Diseño de Pretest-Postest con Grupo de Control Aleatorizado). La población estuvo compuesta por 864 estudiantes de SMP Negeri 1 Purwokerto, de los cuales se seleccionaron 96 estudiantes (M = 13,5 años, DE = 1,0) mediante muestreo aleatorio simple. Los instrumentos incluyeron el Cuestionario de Motivación para el Aprendizaje de la Educación Física (PE-LMQ, Validez = 0,871, Fiabilidad = 0,912), la Prueba de Dígitos de WAIS/WISC (Validez = 0,911, Fiabilidad = 0,943) y la Escala de Autoeficacia Académica (ASES, Validez = 0,889, Fiabilidad = 0,907). Los datos se analizaron mediante pruebas de normalidad, homogeneidad, t de Student pareadas e independientes.
Discusión: Los resultados mostraron que los datos cumplían con los supuestos de normalidad (sig = 0,421) y homogeneidad (sig = 0,519). El aprendizaje basado en RA tuvo un efecto significativo en todos los aspectos medidos (sig = 0,000), mientras que el grupo de control también mostró efectos (sig = 0,041). Se encontró una diferencia significativa entre los grupos (sig = 0,001).
Conclusión: El aprendizaje basado en RA mejora significativamente la motivación, la inteligencia cognitiva y la autoeficacia en la educación física, superando los modelos tradicionales de enseñanza directa.

Palabras clave

Realidad aumentada; inteligencia cognitiva; medios de aprendizaje; motivación para el aprendizaje; autoeficacia.

Introduction

The rapid advancement of digital technologies in the Fourth Industrial Revolution (Education 4.0) has reshaped the educational landscape by integrating tools such as Artificial Intelligence (AI), the Internet of Things (IoT), big data, cloud computing, and Augmented Reality (AR) into teaching and learning environments (Akoramurthy, 2024; Børte & Lillejord, 2024; Chen, 2023; Festiawan et al., 2024; Kilinc-Ata, 2024; Kim, 2024; S Nelson, 2025; Nowfal, 2024; Qureshi et al., 2021; Suhaimi, 2024). These innovations offer educators opportunities to personalize instruction, enhance interactivity, and foster deeper student engagement, particularly through immersive, data-rich, and adaptive learning experiences (Martin, 2020; Tuli et al., 2022; Zainuddin, 2020)

Despite these opportunities, many educational institutions, especially in developing countries, remain reliant on conventional and textbook-based instructional models. This disconnect often leads to diminished student interest, limited participation, and stagnant academic outcomes (Ciloglu & Ustun, 2023; Omarov, 2024; Volioti et al., 2022). In the Indonesian context, these challenges are evident in Physical Education (PE), where traditional teaching methods dominate. Observations and interviews with teachers from Junior High School 1 Purwokerto and Junior High School 2 Purwokerto reveal that PE lessons are still conducted using outdated tools and non-interactive media. Consequently, students frequently express boredom and disengagement during lessons, which negatively affects academic performance. This is confirmed by school records indicating that only 37.25% of students met the Minimum Passing Criteria in the cognitive component of PE learning.

This situation highlights the urgent need for innovative pedagogical strategies that stimulate motivation, foster cognitive development, and build students' academic self-efficacy. One promising approach that has garnered increasing attention is the use of Augmented Reality (AR) in education. AR enables the overlay of digital elements onto the real world, creating interactive and engaging learning environments that can support better concept visualization, promote active participation, and encourage self-directed learning (Cai et al., 2020; Hidayat et al., 2021; Sonya Nelson et al., 2022; Wenk et al., 2023).

In addition to its interactive potential, AR-based learning has shown promising effects in enhancing student motivation (Amores-Valencia et al., 2022; Sabbah et al., 2023; Urban et al., 2022), improving cognitive performance (Celik, 2023; Haryanto, 2024; Ruiz-ariza et al., 2017; Seitz, 2025), and increasing academic self-efficacy (Ciloglu & Ustun, 2023; Yousef, 2021). Moreover, recent studies have demonstrated that AR fosters multisensory learning through visual, auditory, and kinesthetic modalities, thereby reducing cognitive load and deepening understanding (Essmiller et al., 2020; Laurens-Arredondo, 2022; Lin et al., 2023). However, most of these studies are concentrated in STEM fields or higher education contexts, with limited exploration in junior high school physical education particularly in rural and semi-urban Indonesian settings.

Furthermore, existing literature tends to examine the impact of AR on single variables in isolation such as motivation, cognitive intelligence, or self-efficacy without providing an integrative framework that connects these constructs. The lack of studies using a holistic approach that links AR-based learning to all three outcomes simultaneously constitutes a significant research gap, especially in the domain of Physical Education, Sports, and Health.

To fill this gap, the present study aims to evaluate the effectiveness of Augmented Reality (AR)-based learning in enhancing learning motivation, cognitive intelligence, and academic self-efficacy among junior high school students in the Banyumas Residency, Indonesia. This region is ideal for such intervention due to its conventional learning culture and limited exposure to digital learning innovations. Specifically, this research is designed to answer the following questions: 1) Does AR-based learning significantly improve students' learning motivation in physical education?, 2) How does AR-based learning affect students' cognitive intelligence?, and 3) What is the impact of AR-based learning on students' academic self-efficacy compared to conventional instruction?.

Theoretically, this study is grounded in Self-Determination Theory (SDT), which posits that motivation and learning thrive when learners feel autonomous, competent, and connected; and in Cognitive Load Theory (CLT), which emphasizes the importance of reducing extraneous cognitive processing to maximize learning efficiency (Lima et al., 2022; Ramírez-Verdugo, 2021; Varina et al., 2022). The integration of AR is expected to satisfy these psychological and cognitive conditions by offering an immersive, feedback-rich, and learner-centered environment.

Therefore, this study contributes not only empirical evidence on the effectiveness of AR-based learning in physical education but also advances theoretical understanding by linking motivation, cognition, and self-efficacy in one coherent model. The results are anticipated to provide actionable insights for educators, policymakers, and developers interested in leveraging immersive technologies for inclusive and impactful educational innovation.

Method

This study employed a true experimental research design, utilizing a Randomized Pretest-Posttest Control Group Design to rigorously evaluate the effectiveness of Augmented Reality (AR)-based learning in enhancing students' learning motivation, cognitive intelligence, and academic self-efficacy in the context of physical education. This design ensured high internal validity through random assignment, control over confounding variables, and structured pre and post intervention assessments to objectively determine the effect of the treatment.

Participants and Sampling

The research population comprised 864 students from grades VII, VIII, and IX at SMP Negeri 1 Purwokerto, distributed across 27 classes (9 classes per grade). To select participants, the study employed a cluster random sampling technique, wherein entire classes (clusters) were randomly selected rather than individual students. This method was chosen to reflect the natural grouping in educational settings and to enhance logistical feasibility during intervention delivery. From the clusters selected, 96 students were recruited (48 in the experimental group and 48 in the control group), with demographic characteristics of mean age = 13.5 ± 1.0 years, mean height = 155.2 ± 6.5 cm, and mean weight = 45.8 ± 8.2 kg. This approach was intended to create a sample that accurately reflects the broader student body, enabling valid analysis and the ability to generalize the findings.

Procedure

This study employs a true experimental research design using the Randomized Pretest-Posttest Control Group Design to investigate the effect of Augmented Reality (AR) on enhancing learning motivation, cognitive intelligence, and self-efficacy in physical education. Participants are randomly assigned to either the experimental group or the control group to ensure unbiased distribution. Both groups undergo two assessments: a pretest (O1) before the intervention and a posttest (O2) after the intervention. The experimental group receives the AR-based learning intervention (X), while the control group follows conventional learning methods (C).

Table 1. Research Design

Group	Assignment	Pretest	Treatment	Posttest
Experimental	R	O_1	X	O_2
Control	R	O_1	C	O_2

Description:
R : Assignment
O1 : Initial assessment (pretest) using multiple-choice tests and survey questionnaires
O2 : Final assessment (posttest) using multiple-choice tests and survey questionnaires
X : Treatment (Augmented Reality in PE Learning)
C : Conventional Learning Media

Intervention

The experimental group received learning through Augmented Reality (AR)-based media, which was developed using Unity and the Vuforia SDK. The AR content included three-dimensional visualizations, animations, and audio explanations that illustrated key swimming techniques aligned with the Indonesian PE curriculum. The intervention was implemented over a three-week period, with two sessions per week, each lasting 60 minutes. In contrast, the control group received conventional physical education instruction using traditional methods, such as lectures, textbook-based learning, and physical demonstrations by the teacher. No digital or multimedia aids were incorporated. The duration, lesson content, and instructional schedule were identical to those of the experimental group to ensure comparability across treatment conditions.

Table 2. Intervention Schedule and Instructional Activities for Experimental and Control Groups

Meeting	Topic / Learning Objective	Experimental Group (AR-Based Learning)	Control Group (Conventional Learning)
1	Introduction to Swimming and Water Safety + Pretest	Orientation session. Digital pretest on learning motivation, cognition, and self-efficacy. AR animation introduces swimming benefits, safety protocols, and pool environment.	Orientation session. Paper-based pretest on learning motivation, cognition, and self-efficacy. Verbal explanation of swimming rules, safety, and goals.
2	Breathing Techniques and Water Familiarization	AR simulates breathing cycle (inhale through nose, exhale through mouth), water entry, and floating. Real-time app feedback and peer discussion.	Teacher explains and demonstrates basic breathing. Students practice in shallow pool or on dry land, with verbal corrections.
3	Freestyle Arm Movements	AR shows arm strokes in front crawl with animation from different angles. Students imitate using app guidance.	Teacher demonstrates front crawl arm movements. Step-by-step practice with feedback.
4	Freestyle Leg Kicks and Body Streamline	AR overlays demonstrate flutter kicks and proper body alignment in water. Students follow rhythm and visual markers.	Teacher explains and demonstrates leg kicking. Practice using kickboards and peer assistance.
5	Full Stroke Coordination (Arms, Legs, Breathing)	AR simulation integrates full-body movement and breathing coordination. Students refine strokes through repetition and reflection via app.	Teacher guides full-stroke coordination. Group-based practice in lanes, teacher supervision.
6	Assessment: Rules and Application + Posttest	AR-based posttest with interactive quiz and simulations to assess motivation, cognition, and self-efficacy. Reflection via digital portfolio.	Paper-based posttest covering motivation, cognition, and self-efficacy. Final discussion and teacher observation.

Instrument

This study employed three standardized instruments, each selected for their robust psychometric properties and prior validation in educational research. First, to assess learning motivation in the context of physical education, the study utilized the Physical Education Learning Motivation Questionnaire (PE-LMQ), adapted from the Academic Motivation Scale (AMS) developed by (Vallerand, 1992). The original AMS distinguishes between intrinsic motivation, extrinsic motivation, and amotivation and has been widely validated in educational settings. For this study, the PE-LMQ version was contextualized for physical education content based on the structure of AMS and the recommendations by (Ntoumanis, 2001) who applied motivation constructs within sport and physical activity environments. The adapted version achieved strong internal consistency (Cronbach's α = 0.912) and construct validity (CFA = 0.871) during preliminary pilot testing.

Second, to measure cognitive intelligence, specifically short-term and working memory, the Digit Span Test was employed. This test is derived from the Wechsler Adult Intelligence Scale (WAIS-IV) and Wechsler Intelligence Scale for Children (WISC-V), as developed by Wechsler (2008). The Digit Span Test assesses both forward memory (rote memory and attention) and backward memory (working memory and executive function). This instrument is internationally recognized for its reliability and has been validated across cultures and age groups, with reliability coefficients exceeding 0.90 in most standardizations. In this study, the validity was confirmed (0.911), and the internal reliability reached a Cronbach's alpha of 0.943.

Third, academic self-efficacy was measured using the Academic Self-Efficacy Scale (ASES), adapted from the scale developed by (Midgley et al., 2000) as part of the Patterns of Adaptive Learning Scales (PALS) framework. This scale evaluates students' beliefs about their capability to successfully perform academic tasks. The adapted ASES was culturally and linguistically validated for use in the Indonesian junior high school context, resulting in high construct validity (0.889) and internal consistency (Cronbach's α = 0.907). Previous research has demonstrated the scale's sensitivity in detecting changes in self-belief across instructional interventions (Bandura, 1997).

All three instruments were translated into Indonesian using a forward-backward translation procedure and reviewed by three subject matter experts (in psychometrics, physical education, and educational psychology). A pilot study with 30 students was conducted outside the main sample to ensure clarity, reliability, and cultural relevance. Confirmatory factor analysis (CFA) and Cronbach's alpha reliability testing were performed using SPSS 26.

Data collection procedure

The research process consisted of four phases. In the first phase, cluster random sampling was applied, and selected students were assigned randomly to the experimental or control groups. In the second phase, a pretest was conducted to collect baseline data on all three dependent variables. The third phase involved the three-week instructional intervention according to the respective treatment conditions. The final phase was the posttest, using the same instruments as the pretest to measure changes resulting from the intervention. Ethical clearance was obtained from the institutional research ethics committee, and informed consent was collected from all participants and their guardians. Additionally, PE teachers involved in the experimental group underwent a training session to ensure uniform and accurate implementation of the AR technology.

Data analysis

Data were analyzed using SPSS version 26. A Shapiro-Wilk test was used to assess data normality, confirming that the data were normally distributed ($p > 0.05$). Levene's test for equality of variances indicated that the assumptions for homogeneity were met ($p > 0.05$). To examine intra-group differences between pretest and posttest scores, Paired Sample t-Tests were used. Independent Sample t-Tests were conducted to compare posttest scores between the experimental and control groups. A significance threshold of $p < 0.05$ was set for all analyses. All statistical assumptions for parametric testing were tested and satisfied

Results

The data obtained in this study is the value of students' learning motivation, cognitive intelligence and self-efficacy, with the following data description:

Students Learning Motivation Data

Table 2 presents data on learning motivation, measured in terms of intrinsic and extrinsic motivation, for both the experimental and control groups before and after the intervention. The experimental group (N = 48) exhibited a significant increase in intrinsic motivation, with the pretest mean score of 65.4 ± 5.6 (ranging from 55 to 75) rising to a posttest mean of 87.1 ± 6.1 (ranging from 76 to 95). In contrast, the control group (N = 48) showed only a moderate improvement, with the pretest mean of 64.9 ± 5.9 (ranging from 54 to 76) increasing to a posttest mean of 72.5 ± 5.8 (ranging from 61 to 82). Similarly, extrinsic motivation in the experimental group improved substantially, with a pretest mean of 65.0 ± 6.0 (ranging from 54 to 75) rising to a posttest mean of 85.8 ± 6.4 (ranging from 74 to 94). These findings indicate that the intervention had a notable impact on enhancing both intrinsic and extrinsic motivation in the experimental group, whereas the control group experienced only limited gains.

Table 2. Learning Motivation Data

Aspect	Group	N	Pretest (Mean ± SD)	Min Pretest	Max Pretest	Posttest (Mean ± SD)	Min Posttest	Max Posttest
Intrinsic Motivation	Experimental	48	65.4 ± 5.6	55	75	87.1 ± 6.1	76	95
	Control	48	64.9 ± 5.9	54	76	72.5 ± 5.8	61	82
Extrinsic Motivation	Experimental	48	65.0 ± 6.0	54	75	85.8 ± 6.4	74	94
	Control	48	64.7 ± 6.2	53	76	72.1 ± 6.0	60	81

Student Cognitive Intelligence Data

Table 3 presents data on cognitive intelligence, specifically assessing forward and backward memory, for both the experimental and control groups before and after the intervention. In the forward memory aspect, the experimental group (N = 48) exhibited a significant improvement, with the pretest mean score of 32.5 ± 3.4 (ranging from 28 to 38) increasing to a posttest mean of 45.2 ± 3.9 (ranging from 40 to 50). In contrast, the control group (N = 48) showed only a modest increase, with a pretest mean of 32.1 ± 3.6 (ranging from 27 to 37) rising to a posttest mean of 38.5 ± 3.5 (ranging from 33 to 44). A similar pattern was observed in backward memory, where the experimental group demonstrated substantial gains, improving from a pretest mean of 30.2 ± 3.1 (ranging from 25 to 36) to a posttest mean of 43.0 ± 3.7 (ranging from 37 to 49). These findings indicate that the intervention had a strong positive impact on enhancing both forward and backward memory performance in the experimental group, whereas the control group exhibited only limited progress.

Table 3. Cognitive Intelligence Data

Aspect	Group	N	Pretest (Mean ± SD)	Min Pretest	Max Pretest	Posttest (Mean ± SD)	Min Posttest	Max Posttest
Forward Memory	Experimental	48	32.5 ± 3.4	28	38	45.2 ± 3.9	40	50
	Control	48	32.1 ± 3.6	27	37	38.5 ± 3.5	33	44
Backward Memory	Experimental	48	30.2 ± 3.1	25	36	43.0 ± 3.7	37	49
	Control	48	30.0 ± 3.3	24	35	37.2 ± 3.4	32	42

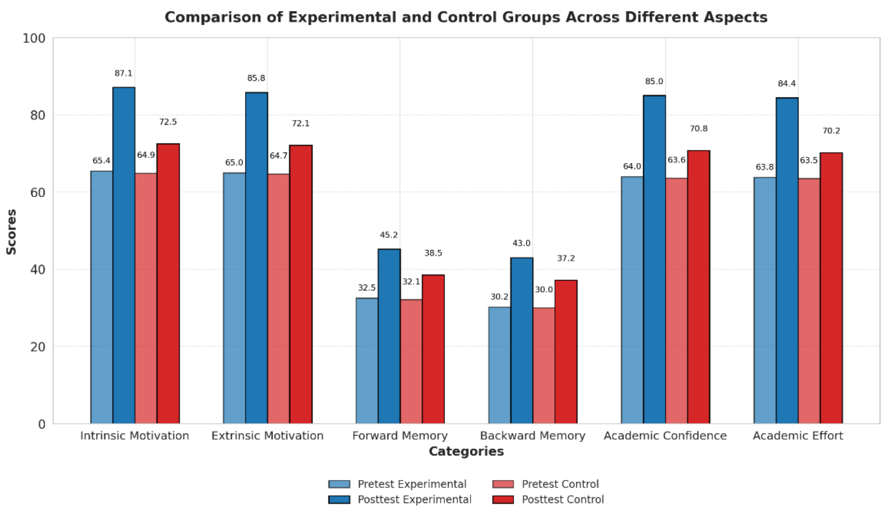
Student Self Effficacy Data

Table 4 presents data on self-efficacy, specifically measuring academic confidence and academic effort, for both the experimental and control groups before and after the intervention. In terms of academic confidence, the experimental group (N = 48) demonstrated a substantial improvement, with the pretest mean score of 64.0 ± 6.1 (ranging from 53 to 75) increasing to a posttest mean of 85.0 ± 6.5 (ranging from 72 to 95). In contrast, the control group (N = 48) showed only a moderate increase, with a pretest mean of 63.6 ± 6.2 (ranging from 52 to 74) rising to a posttest mean of 70.8 ± 6.1 (ranging from 58 to 80). A similar trend was observed in academic effort, where the experimental group exhibited a significant gain, improving from a pretest mean of 63.8 ± 6.0 (ranging from 52 to 75) to a posttest mean of 84.4 ± 6.3 (ranging from 71 to 94). These results suggest that the intervention was highly effective in enhancing both academic confidence and effort in the experimental group, while the control group experienced only limited progress.

Table 4. Self-Efficacy Data

Aspect	Group	N	Pretest (Mean ± SD)	Min Pretest	Max Pretest	Posttest (Mean ± SD)	Min Posttest	Max Posttest
Academic Confidence	Experimental	48	64.0 ± 6.1	53	75	85.0 ± 6.5	72	95
	Control	48	63.6 ± 6.2	52	74	70.8 ± 6.1	58	80
Academic Effort	Experimental	48	63.8 ± 6.0	52	75	84.4 ± 6.3	71	94
	Control	48	63.5 ± 6.1	51	73	70.2 ± 6.0	57	79

Figure 1. Comparison of Experimental and Control Group



Hypothesis Testing Results

The normality test results indicate that the data are normally distributed, with a Shapiro-Wilk significance value of 0.421, confirming that parametric tests can be applied. The homogeneity test results show that the data are homogeneous, with a Levene's Test significance value of 0.519, indicating that both groups have similar variance distributions.

Table 5. Paired Sample T-Test and Cohen's d Results

Group	Mean Difference	SD (Difference)	t-value	p-value	Cohen's d
Experimental	21.7	2.142	-6.983	p < .001	10.13
Control	7.6	1.875	-3.251	p = .041	4.05

The paired t-test showed statistically significant differences in both groups. However, the effect size (Cohen's d) in the experimental group was extremely large (d = 10.13), suggesting a powerful practical effect of the AR-based learning intervention. In the control group, the effect size was also large (d = 4.05), but markedly smaller than in the experimental group. These results confirm that AR had a substantial and consistent impact on the improvement of learning motivation, cognitive performance, and self-efficacy.

Table 6. Independent t-test

Measurement Aspect	Mean (Experimental)	Mean (Control)	t-value	Sig. (2-tailed)
Learning Motivation	86.5	72.3	5.214	0.001
Cognitive Intelligence	88.2	74.8	6.037	0.001
Self-Efficacy	84.7	70.5	5.872	0.001

The independent t-test results reveal a significant difference between the experimental and control groups across all measured variables, with p = 0.001 in each case. These results confirm that augmented reality learning is more effective than conventional learning methods in improving students' learning motivation, cognitive intelligence, and self-efficacy.

Discussion

The findings of this study provide compelling evidence that Augmented Reality (AR)-based learning significantly enhances students' learning motivation, cognitive intelligence, and academic self-efficacy in physical education. These improvements were particularly prominent in the experimental group, which outperformed the control group in all measured dimensions. Rather than merely reaffirming these results, this discussion seeks to interpret them in light of relevant literature, examine unexpected trends, evaluate alternative explanations, and reflect on the methodological limitations of the study.

The positive impact of AR-based learning on learning motivation aligns with previous studies that emphasize the motivational benefits of immersive and interactive learning environments. For instance, (Yousef, 2021) and (Amores-Valencia et al., 2022) demonstrated that AR increases students' intrinsic interest by providing real-time interaction and immediate feedback. In the current study, students in the AR group reported significantly higher posttest scores for both intrinsic and extrinsic motivation. This can be explained through the lens of Self-Determination Theory (SDT), which suggests that AR fosters autonomy and competence by allowing students to control their pace and receive personalized feedback key factors that enhance motivation (Lima et al., 2022).

With regard to cognitive intelligence, the significant gains observed in the experimental group especially in working memory (backward digit span) support prior findings by (Ruiz-ariza et al., 2017) and (Lin et al., 2023), who reported that AR's multisensory features reduce extraneous cognitive load and facilitate deeper mental processing. Unlike traditional instruction, the AR approach integrated visual, auditory, and kinesthetic stimuli, which may have activated multiple neural pathways, reinforcing memory encoding and retrieval. This is consistent with Cognitive Load Theory (CLT), which posits that well-designed multimedia can reduce unnecessary mental strain and enhance learning efficiency (Wenk et al., 2023).

Regarding self-efficacy, our findings resonate with studies by (Ciloglu & Ustun, 2023) and (Cai et al., 2020), who argue that AR fosters a sense of achievement and control over learning outcomes. The experimental group not only reported higher academic confidence and effort but also demonstrated behavioral engagement during the intervention. These improvements can be attributed to the experiential nature of AR, which allows students to practice skills in safe, low-pressure environments, thereby increasing their belief in their own capabilities.

This study contributes to the literature by examining all three constructs motivation, cognition, and self-efficacy in an integrated model within physical education. While prior research often investigates these variables in isolation, this study's holistic approach provides a more comprehensive understanding of how AR impacts learning. Furthermore, most AR-related studies have focused on STEM education or higher education settings (Majeed & ALRikabi, 2022), whereas this study fills a notable gap by focusing on junior high school students in a physical education context within a developing country.

While it is tempting to state that "AR bridges theory and practice," it is essential to ground such claims in empirical observation. In this study, AR helped students visualize correct techniques (e.g., freestyle swimming coordination), but this effect likely stemmed from the guided visualization and feedback loops, rather than AR itself. The novelty of the technology may have also temporarily elevated engagement a phenomenon known as the novelty effect which must be disentangled in future research through longitudinal designs (Lampropoulos et al., 2022)

Additionally, while AR clearly benefited the experimental group, the control group also showed significant though smaller gains, indicating that learning occurred regardless of instructional media. This highlights the influence of other potential variables, such as teacher competence, peer interaction, or instructional time, which were not the primary focus of this study but warrant further investigation.

Several limitations merit attention. First, the sample was drawn from a single school in one geographic region, limiting generalizability. Second, while the AR intervention was described broadly, a detailed breakdown of the AR components, instructional scripts, and student interaction logs was not provided details that could help others replicate or improve upon this model. Third, the novelty of the AR experience may have artificially inflated motivation scores, especially during the initial sessions. Fourth, teacher influence was not controlled across conditions, which may have affected outcomes despite standardized lesson plans.

Future research should address these limitations by including multi-site samples, providing richer qualitative data (e.g., student interviews or AR usage logs), and exploring the long-term effects of AR on retention, transfer of skills, and behavioral outcomes. It would also be valuable to investigate how different AR design features such as gamification, avatar customization, or adaptive scaffolding modulate the impact on learning.

In sum, this study underscores the multifaceted benefits of AR in physical education by demonstrating statistically significant gains in motivation, cognitive performance, and self-efficacy. These findings not only replicate but also extend previous work by offering an integrated framework for understanding AR's educational impact in under-researched contexts. By aligning instructional innovation with psychological and cognitive theories, AR-based learning emerges as a promising strategy for inclusive, engaging, and effective physical education instruction.

Conclusions

This study provides evidence that augmented reality (AR) learning can enhance students' motivation, cognitive development, and self-efficacy in physical education settings. Rather than merely reiterating these findings, the results collectively suggest that AR facilitates a more engaging, student-centered learning environment that supports both affective and cognitive learning processes. This interactive approach may foster deeper student engagement, promote autonomy in learning physical activities, and create a bridge between abstract concepts and real-world applications.

From a practical standpoint, educators are encouraged to integrate AR technologies as a supplementary tool to traditional instruction, particularly to enrich kinesthetic and visual learning experiences. Schools and policymakers should consider investing in AR infrastructure and teacher training to maximize its pedagogical potential, especially in contexts where student engagement in physical education is traditionally low.

Future research should examine the long-term effects of AR on physical activity adherence, motor skill development, and learning retention. It is also essential to investigate how AR tools can be adapted for different educational levels, learning abilities, and diverse classroom contexts. Furthermore, addressing implementation barriers such as technological accessibility, teacher readiness, and curriculum integration is critical for sustainable adoption.

Importantly, while this study identifies positive associations between AR learning and various student outcomes, the conclusions should be interpreted with caution. Given the study's design, causal inferences are limited, and other contextual factors (e.g., novelty effects, instructor influence) may have contributed to the observed outcomes. Subsequent studies employing experimental or longitudinal designs are necessary to validate and expand upon these preliminary findings.

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