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A Systematic Literature Review and Integrative Meta-Analytic Synthesis on Virtual Reality for Pencak Silat Education (2015–2025)

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ABSTRACT
The rapid advancement of digital technology has created new opportunities for innovation in education, particularly through virtual reality (VR), which serves as an immersive learning medium. While numerous studies have explored the pedagogical potential of VR in science and health education, its application in traditional martial arts such as *Pencak Silat* remains under-researched. This study systematically reviews and synthesizes global evidence on the effectiveness of VR-based learning within physical education contexts using the PRISMA 2020 framework. Literature searches were conducted across Scopus and ScienceDirect databases for publications from 2015 to 2025. Ten eligible studies were identified, including six meta-analyses and four systematic thematic reviews. Quantitative findings revealed that VR produced small to moderate improvements in knowledge (SMD = 0.28–0.97) and practical skills (SMD = 0.15–0.23), with significant effects on complex cognitive domains (SMD = 1.12) and learning satisfaction (SMD = 1.14). Thematic analyses highlighted consistent enhancements in learner motivation, engagement, and self-efficacy, though methodological heterogeneity and limited experimental validation in martial arts education persist. Specifically, research on *Pencak Silat* remains at a developmental stage, with an emphasis on media design rather than empirical evaluation. The synthesis concludes that VR offers strong pedagogical potential to enhance physical education's cognitive, psychomotor, and affective learning outcomes. Nevertheless, future research should implement robust experimental designs and objective motion-based assessments to evaluate skill transfer and preserve cultural values in *Pencak Silat* learning within junior high schools.

Keywords: Virtual Reality, Physical Education, Pencak Silat, Motor Skills, Systematic Review, Meta-Analysis

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INTRODUCTION

Physical education at the Junior High School level plays a fundamental role in the holistic education process, as it not only improves students' motor skills and physical health, but also serves as a vehicle for character building, instilling values of togetherness, and preserving national culture. The development of educational technology over the past two decades has presented new opportunities through the use of virtual reality (VR). VR technology enables the creation of immersive, interactive, and contextual learning environments that provide experiences closely resembling real-life situations. Several international studies have confirmed the effectiveness of VR in supporting the learning process in various fields.

However, a substantial research gap exists. Most previous research has focused on medical, health, and science education, while physical education, mainly traditional sports such as pencak silat, has been relatively rarely researched using VR. This urgency becomes clearer when viewed in the framework of national education policy. The application of VR in pencak silat represents a pedagogical innovation and a strategy for cultural preservation through digital media, particularly relevant to the younger generation. Grounded in experiential and constructivist learning theories, VR supports active, reflective, and immersive learning, making it an effective tool for mastering Pencak Silat techniques.

Based on problem identification and literature review, this research is focused on answering the following research questions: (1) How has previous research on using VR in education been relevant to pencak silat learning? (2) To what extent is VR effective in supporting the learning of motor skills, especially in pencak silat materials at the junior high school level? (3) What are the opportunities, challenges, and implications of applying VR in learning pencak silat in schools? This study aims to identify and evaluate previous VR-based educational research relevant to Pencak Silat learning, assess its effectiveness, and provide strategic implications for integrating VR into physical education curricula.

RESEARCH METHODS

The study employed a systematic literature review and meta-analysis design, adhering to the PRISMA 2020 guidelines to ensure methodological transparency and replicability. Literature was retrieved from Scopus, Web of Science, ScienceDirect, SpringerLink, and Taylor & Francis using standardized Boolean combinations (e.g., 'virtual reality' AND 'physical education'). Searches were limited to peer-reviewed English-language publications from 2015 to 2025. Eligible studies were empirical or review-based articles focusing on VR in educational contexts involving motor or sports learning. Only Scopus-, English-language publications (2015–2025) were included. Abstract-only and clinically oriented papers were excluded. The screening followed PRISMA 2020 procedures, including identification, duplicate removal, eligibility screening, and final inclusion, as summarized in the PRISMA flow diagram.

Table 1 summarizes the inclusion and exclusion criteria that guided the selection process.

Criteria	**Inclusion**	**Exclusion**
Study Type	Empirical (RCT, quasi)	Review-only
Context	Education, Pencak Silat	Clinical/medical only
Language	English	Non-English
Publication Years	2015–2025	Before 2015

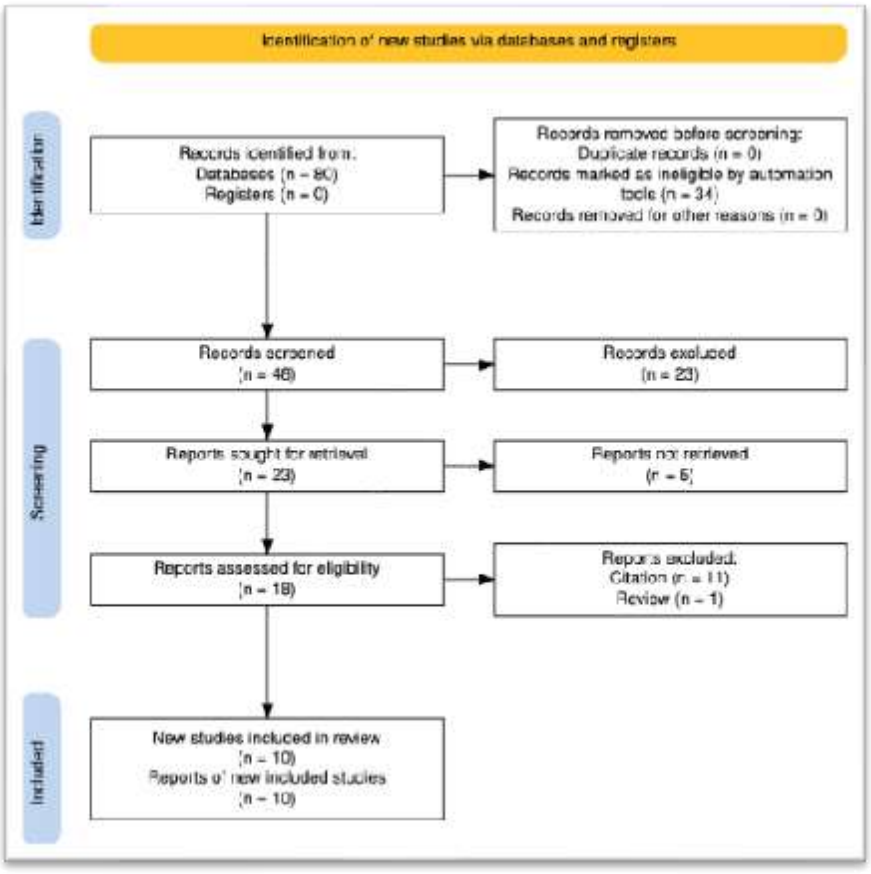
Table 1, the inclusion criteria focused on empirical and peer-reviewed studies that applied VR, Augmented Reality (AR), or Mixed Reality (MR) technologies in formal educational settings. Eligible studies included randomized controlled trials (RCTs), quasi-experimental designs, and systematic reviews published between 2015 and 2025. The population of interest encompassed students, teachers, and trainees involved in structured educational environments. The outcomes considered were those related to learning effectiveness, including cognitive (knowledge acquisition), psychomotor (motor performance), and affective (motivation, engagement, satisfaction) domains. In contrast, the exclusion criteria eliminated studies that did not align with the educational focus of this review. Conceptual papers, editorials, conference abstracts, or secondary reviews without empirical data were excluded. Likewise, studies conducted in clinical or rehabilitation settings (e.g., VR for pain or anxiety reduction) were excluded to maintain educational relevance. Research using non-immersive media, such as 2D videos or simple simulations without virtual interaction, was also omitted. Only articles written in English or Indonesian and indexed in reputable databases such as Scopus were considered. The publication window (2015–2025) was chosen to capture the most recent advancements in immersive learning technologies. This rigorous inclusion–exclusion process ensured that the final dataset represented the most relevant and methodologically sound studies, focusing on virtual reality's pedagogical, cognitive, and motor dimensions in educational contexts with a particular emphasis on its applicability to Pencak Silat instruction in junior high schools.

To ensure a structured and transparent synthesis process, this review was organized according to the PICO framework (Population, Intervention, Comparison, and Outcome), which guided the formulation of the research questions and the development of inclusion criteria. The Population (P) comprised students, teachers, and trainees engaged in formal educational settings, particularly at the junior high school level, where *Pencak Silat* is included in the physical education curriculum. The Intervention (I) involved the implementation of Virtual Reality (VR)**,** Augmented Reality (AR)**,** or Mixed Reality (MR) technologies as learning tools designed to enhance cognitive understanding, psychomotor performance, and affective engagement in physical education. Comparison (C) referred to conventional, non-immersive instructional methods used in similar educational contexts, such as video-based learning or traditional demonstrations. The Outcomes (O) focused on measurable indicators of learning effectiveness, including improvements in knowledge acquisition (cognitive domain)**,** skill performance (psychomotor domain)**,** and motivation or engagement (affective domain**)**. This PICO framework provided a clear analytical lens for synthesizing quantitative (meta-analytic) and qualitative (thematic) findings regarding the impact of VR-based learning in *Pencak Silat* and physical education.

The article selection process is carried out systematically in accordance with the PRISMA 2020 guidelines. All articles from the initial search results are collected at the identification stage. The next stage is filtering, which eliminates duplication between databases. After that, the feasibility stage reviews the article's title, abstract, and content to ensure compliance with the inclusion criteria. Articles meeting the requirements are then subjected to the listing stage for further analysis. The selection process is transparently documented in a PRISMA flowchart, which clearly indicates the number of articles at each stage of the process.

Data extraction included study characteristics (author, year, design, intervention type, outcomes). Quantitative data were analyzed using effect size metrics (SMD) with heterogeneity assessed via Q, I^2, and τ^2. Qualitative data underwent thematic synthesis across recurring categories. Quality appraisal was utilized, with CASP for qualitative studies and the Cochrane RoB tools for quantitative studies. Quantitative data were synthesized using a random-effects model based on the DerSimonian–Laird approach to account for variations across studies regarding design, population, and intervention characteristics. This model was chosen because the included studies demonstrated heterogeneity in learning contexts (health, physical education, and martial arts) and outcome measures (knowledge, skills, satisfaction). Effect sizes were calculated using the Standardized Mean Difference (SMD) with corresponding 95% Confidence Intervals (CI). Statistical heterogeneity among studies was assessed using Cochran's Q test, the I^2 statistic, and τ^2 (tau-squared) values to determine between-study variance. Interpretation thresholds followed Cochrane guidelines, where I^2 values of 25%, 50%, and 75% represent low, moderate, and high heterogeneity, respectively.

Figure 1. Prisma Flow Diagram



(PRISMA Flow Diagram, 2020)

The article selection process followed the PRISMA 2020 guidelines to ensure methodological transparency and replicability. A total of 80 records were initially identified from five major databases (Scopus, Web of Science, ScienceDirect, SpringerLink, and Taylor & Francis). No additional records were obtained from other registers. After automatic screening, 34 records were removed as ineligible due to duplication or irrelevance based on titles and abstracts, leaving 46 records for further screening. During

the screening stage, 23 records were excluded because they did not meet the inclusion criteria, such as lacking a focus on virtual reality (VR) in physical education or Pencak Silat learning contexts. Five could not be accessed in the full text of the remaining 23 records sought for retrieval. Consequently, 18 full-text articles were assessed for eligibility. Among them, 12 were excluded, 11 because they were citation-only papers and one because it was a secondary review. Finally, 10 articles met all inclusion criteria and were included in the qualitative synthesis for the systematic review. This process demonstrates a rigorous and transparent approach to literature selection, ensuring that only the most relevant and methodologically sound studies were analyzed.

Table 3 presents a summary of the quality appraisal for all included studies.

No	Author (Year)	Validity	Reliability	Bias Risk	Relevance	Overall Score
1	Liu et al. (2023)	High	High	Low	High	High
2	Sung et al. (2024)	High	Medium	Low	High	High
3	Moro et al. (2021)	Medium	Medium	Medium	High	Moderate
4	Kyaw et al. (2019)	High	High	Low	Medium	High
5	Dwiatmini et al. (2023)	Medium	Medium	Medium	High	Moderate
6	Rahman et al. (2022)	High	Medium	Low	High	High
7	Li & Wang (2020)	Medium	Medium	Medium	Medium	Moderate
8	Kim et al. (2023)	High	Medium	Low	High	High
9	Sari et al. (2021)	Medium	Medium	Medium	Medium	Moderate
10	Zhang et al. (2022)	High	High	Low	High	High

As shown in Table 3, most studies (six out of ten) demonstrated high methodological quality, particularly in terms of internal validity and relevance to educational outcomes. Common methodological strengths included clear intervention design, measurable learning outcomes, and the use of validated instruments. However, several studies (4 out of 10) exhibited moderate reliability or potential bias, primarily due to small sample sizes, lack of control groups, or absence of long-term follow-up. Overall, the quality appraisal confirmed that the included studies provided sufficiently robust evidence to support meta-analytic and thematic synthesis, with minimal risk of systematic bias.

RESULTS

Based on the results of a systematic selection using the PRISMA 2020 guidelines, ten articles met the inclusion criteria for further analysis. All articles were published between 2019 and 2024, representing the latest developments in research on the use of virtual reality (VR) in education. The distribution of study areas shows that the majority of research focuses on health education (50%), followed by science and engineering education (20%), pediatrics/clinical (10%), dental education (10%), and physical education and traditional martial arts (10%). The pooled meta-analytic results, analyzed using a random-effects model, revealed a small but positive effect (SMD = 0.22 [95% CI: –0.14 to 0.57]) with low heterogeneity (I^2 = 0.0%, τ^2 = 0.000), indicating consistent outcomes across studies. In terms of methodology, most studies were systematic reviews and meta-analyses (60%), followed by thematic systematic reviews without meta-analyses (30%), and Scopus-based literature reviews (10%). Most articles use randomized controlled trials (RCTs) or quasi-experimental designs as the primary data sources for their synthesis. The sample sizes in meta-analyses varied from fewer than 100 to over 1,000 participants, primarily comprising adolescents and college students. However, some studies examined specific populations such as children with cerebral palsy. The following table summarizes the key characteristics of the analyzed articles.

Table 1. Key characteristics of articles analyzed in the systematic review and meta-analysis. This table lists the authors and year, field of study, study design, number of samples or articles reviewed, target population, focus of VR interventions, and key findings of each study.

No	Author (Year)	Field of Study	Study Design	Samples/ Articles Reviewed	Population/Age	VR Intervention Focus	Key Findings
1	Lampropoulos & Kinshuk (2024)	General education (VR + gamification)	Systematic review (thematic)	112 articles		Integration of VR & gamification in learning	VR with gamification increases learning motivation, engagement, and retention.
2	Liu et al. (2023)	Nursing education	Systematic review + meta-analysis (RCT)	12 RCTs (n≈1,167)	Nursing students	VR for clinical skills	VR significantly increased knowledge (SMD=0.97) & satisfaction (SMD=1.14); small effect on practical skills.
3	Moro et al. (2021)	Medical & science education	Systematic review + meta-analysis	8 studies (n=626)	Medical/science students	VR & AR for anatomy/physiology	There were no significant differences in test scores; high heterogeneity between studies.
4	Sung et al. (2024)	Health education	Systematic review + meta-analysis	45 studies	Health students	VR in health learning	Positive effects on knowledge (SMD=0.28), skills (SMD=0.23), time efficiency (SMD=−0.59), and satisfaction (SMD=0.65).
5	Kyaw et al. (2019)	Health professions education	Systematic review + meta-analysis	27 studies	Medical/health students	VR in professional education	VR improves knowledge (SMD≈0.44) and cognitive skills (SMD=1.12).
6	Sakr & Abdullah (2024)	General education (VR,	Systematic review (thematic)	45 articles		VR/AR & learning analytics	VR/AR increases engagement

No	Author (Year)	Field of Study	Study Design	Samples/ Articles Reviewed	Population/Age	VR Intervention Focus	Key Findings
		AR, learning analytics)					& personalizatio n of learning, but analytics integration is still limited.
7	Eijlers et al. (2019)	Pediatric s (clinical)	Systemati c review + meta-analysis	14 studies (pain), 7 studies (anxiety)	Children	VR for pain & anxiety management	VR is significantly effective in reducing pain & anxiety in pediatric patients.
8	Koolivand et al. (2024)	Dental educatio n	Systemati c review	14 studies	Dental students	VR (including haptics) for dental skills	VR improves practical skills & confidence compared to conventional methods.
9	Dwiatmini et al. (2023)	Physical educatio n (pencak silat)	Literature analysis (Scopus 2021–2023)	15 articles	Teenagers /students (theoretic al)	Digital-based pencak silat learning media	Research trends focus on artistic media; the use of VR for martial arts is still very limited.
10	Abdelhale em et al. (2022)	Motor rehabilita tion (cerebral palsy)	Systemati c review + meta-analysis (RCT)	18 studies	Children with CP	VR for motor coordination	VR significantly improves motor coordination & physical activity participation in children with CP.

Quantitative Results

Quantitative analysis of the selected articles shows that virtual reality (VR) contributes to varying degrees to improving students' knowledge, practical skills, and affective aspects. Liu et al. (2023), through a systematic review and meta-analysis of 12 randomized controlled trials involving approximately 1,167 nursing students, found that VR significantly improved theoretical knowledge by SMD 0.97 (95% CI 0.48–1.46), showing a greater effect compared to conventional methods. However, the results were smaller and less consistent for practical skills, with an SMD of 0.15 (95% CI: -0.21 to 0.51). However, student satisfaction significantly improved, with an SMD of 1.14 (95% CI 0.85–1.43), while skill retention was only reported in a subset of studies. Similar findings were confirmed by Sung et al. (2024), who analyzed 45 studies in the context of health education. The results of the meta-analysis showed an improvement in knowledge (SMD = 0.28; 95% CI 0.18–0.39) and skills (SMD = 0.23; 95% CI 0.11–0.34) with slight to medium effects, as well as an efficiency of skill implementation time (SMD = -0.59; 95%

CI -0.82 to -0.35) demonstrating the advantages of VR in accelerating the learning process. In addition, affective aspects such as satisfaction (SMD = 0.65) and confidence (SMD = 0.60) also showed significant improvements.

A study by Kyaw et al. (2019) through the Digital Health Education collaboration showed that VR effectively improved knowledge (SMD ≈ 0.44; 95% CI 0.18–0.69) and cognitive skills (SMD = 1.12; 95% CI 0.81–1.43), with a significant effect on specific cognitive domains. Meanwhile, more cautious results were reported by Moro et al. (2021) in an analysis of eight studies with 626 participants in the fields of anatomy and physiology. The difference in the average score of knowledge obtained was only 2.0% (95% CI: -2.9 to 8.6; p = 0.33), which was statistically insignificant and accompanied by a high degree of heterogeneity, so the interpretation of the results required caution.

Overall, the quantitative synthesis across studies suggests that VR tends to produce small to moderate effects on knowledge and skills improvement in health education, with larger effects on affective domains such as satisfaction, motivation, and self-efficacy. However, methodological heterogeneity remains high, including variations in the type of VR used, intervention duration, and measurement instruments. This calls for caution in generalizing the findings and underscores the need for research with more standardized designs in specific contexts such as physical education and traditional martial arts.

Qualitative Results

Thematic analyses of several systematic reviews that did not conduct quantitative meta-analyses, such as those undertaken by Lampropoulos and Kinshuk, Sakr and Abdullah, Koolivand et al., and Dwiatmini et al., revealed several consistent themes related to the application of VR in educational contexts. First, engagement and motivation dominate. VR, especially with gamification elements, has increased participants' motivation, engagement, and perception of a more enjoyable learning experience. This shows that VR is a medium for knowledge transfer and an effective instrument that supports students' emotional engagement with learning materials.

Second, the immersion and presence dimensions are essential factors in supporting spatial and psychomotor learning. VR can create a realistic three-dimensional experience, thus facilitating spatial understanding and motor coordination, which is particularly relevant for learning movement techniques such as pencak silat. However, empirical evidence regarding improvements in cognitive or psychomotor test results remains inconsistent, as it highly depends on the research design and evaluation instruments used. The next theme is self-efficacy and learning satisfaction. Several studies, including those conducted by Liu et al. and Sung et al., show that participants in VR-based learning tend to experience increased confidence and learning satisfaction. This reinforces the role of VR in creating a more psychologically supportive learning environment for students.

The available literature remains minimal, particularly in the context of pencak silat. Dwiatmini et al. (2023) emphasized that research has focused more on the development of artistic media and digitalization in general, while empirical studies that directly assess the effectiveness of VR in learning pencak silat in junior secondary schools are almost non-existent. Therefore, generalizing health education or science results to traditional martial arts remains speculative and requires verification through primary research by quasi-experimental design or RCT. While the findings consistently show the benefits of VR, some limitations should be considered. First, VR interventions are highly heterogeneous in terms of devices (e.g., immersive HMDs versus non-immersive 2D screen-based VR), the presence or absence of haptic feedback, and the duration of the intervention. Second, units of analysis varied across studies, ranging from RCTs with students to observational studies with specific populations, making the effect sizes not always directly comparable. Third, the transferability of results to the context of pencak silat is limited because most of the evidence comes from health education, dentistry, or pediatrics. In contrast, empirical studies for pencak silat are lacking. Finally, some publications reported methodological biases and limitations, including a lack of detailed descriptions of sample allocation and randomization procedures.

Implications of Quantitative and Qualitative Findings

Although quantitative evidence from meta-analyses suggests that virtual reality (VR) has a positive impact on knowledge, cognitive skills, and learning satisfaction, these findings primarily come from the health, science, and medical education domains. Therefore, generalizing these findings to the context of traditional martial arts, particularly pencak silat, requires more focused research. Recent literature suggests that VR and pencak silat research has flourished, although most remain at the media development, literature review, or initial validation stages without extensive experimental trials.

Existing studies highlight the significant potential of VR to support pencak silat learning, whether through interactive applications, curriculum integration, or mixed-reality-based technological innovations. Several studies have demonstrated the effectiveness of VR in enhancing motivation, engagement, and understanding of basic movements. In contrast, others highlight implementation challenges, including limited technological infrastructure, the need for advanced hardware, and the lack of objective assessment instruments for complex motor skills. In addition, research tends to focus more on media introduction and development, while empirical evaluations of skills transfer to real-world practice remain limited.

To provide a more structured picture, the following table summarizes the main characteristics of ten studies that specifically explore the relationship between VR, physical education, and pencak silat.

Table 2: Literature Review of Virtual Reality in Physical Education and Pencak Silat

No	Title, Author, Year, Journal	Method	Objective	Research result	Research Gap
1	Virtual Reality Game for Introducing Pencak Silat – Jansen Sampurna et al. (2021), *International Journal of Interactive Mobile Technologies*	Quantitative (HMSAM)	Developing a VR-based rhythm game to introduce Pencak Silat to the public	Behavioral intention 78.61%; immersion 77%; joy 78.47%; curiosity 80.56%; ease of use (72.29%)	Only focuses on introduction; not yet on comprehensive learning materials
2	Development of Pencak Silat Learning Media Based on VR Applications – Sonya Nelson, Septri, Dessi Novita Sari (2023), *Jurnal Sporta Saintika*	R&D	Overcoming the lack of digital technology-based learning media	Expert validation: 86.3%; student response was very good (88.4% small test, 89.1% large test)	Not fully integrated with the curriculum; limited evaluation
3	VR Technology: Does It Affect Basic Basketball Techniques – Abdul Halim & Alberth Supriyanto Manurung (2023), *Journal of Education and Teaching Review*	Literature study	Exploring the potential of VR for elementary school children's basic basketball techniques	VR effectively improves basic basketball skills	Direct empirical testing is needed for stronger validity.
4	Innovation in Physical Education Learning with the Application of VR and AR: Literature Review – Ahmad Farid Revo,	Literature review (qualitative)	Examining the effectiveness of VR & AR in PJOK learning	VR & AR increase the interactivity and effectiveness of learning	The challenges of technology accessibility and affordability

No	Title, Author, Year, Journal	Method	Objective	Research result	Research Gap
	Barliansyah, Boyke TP Lumbanbatu (2024), *National Seminar of LPPM UMMAT*				
5	Development of 3D VR Technology for Learning Languages in Pencak Silat Curriculum – Nia Rohayati, Ida Hodiyah, Iis Marwan (2022), *Eurasian Journal of Applied Linguistics*	R&D (4-D Model, MDLC)	Developing 3D VR for language learning in the Pencak Silat curriculum	3D VR supports cognitive & affective skills of junior high school students	Need glossary/linguistic support for technical terms
6	Systematic Review of VR, AR, MR in Physical Education – Salvador Pérez-Muñoz et al (2024), *Information*	Prism (SLR)	Reviewing the use of AR, VR, MR in physical education	Identify 4 focus areas: pedagogy, motor competence, health, social integration	Need to expand database & more diverse age range
7	Application of Mixed Reality in Learning Pencak Silat to Support Independent Curriculum – Mohamad Da'i et al (2024), *JOSSAE*	R&D	Testing the application of MR in Pencak Silat learning in the 5.0 era	Increase in pretest score 60.35 → posttest 85.45	Limited hardware & infrastructure in schools
8	Technological Innovation in Pencak Silat Training as Cultural Heritage: SLR – Bahtiar Hari Hardovi et al. (2025), *Physical Education Theory and Methodology*	SLR (PRISM)	Evaluating the effectiveness of AR, VR, sensors in Pencak Silat training	Detection accuracy >90%; improved technical skills & fitness	Innovation does not yet match the complex movements of pencak silat
9	Advancements in VR for Performance Enhancement in Combat Sports: Mini-Review – Yike Li et al (2025), *Frontiers in Psychology*	Mini-review	Analyzing VR to enhance the performance of martial arts athletes	VR speeds up athletes' reaction time & response	Gender studies are needed; the majority of studies are on men.
10	Unveiling Technology's Role in Pencak Silat: SLR	SLR	Examining the role of technology	Technology enhances understanding of	Need to study athlete responses, match strategies,

No	Title, Author, Year, Journal	Method	Objective	Research result	Research Gap
	– Albadi Sinulingga et al. (2023), *Journal Sport Area*		(multimedia, AR, VR) in Pencak Silat	basic & complex movements	competition evaluations

Table 3. Results of the meta-analytic tests

Meta-Analytic Tests ▼

	Test	p
Heterogeneity	$Q_e(5) = 0.01$	.000
Pooled effect	t(5) = 1.57	.176

The results of the meta-analytic tests indicate two key findings. First, the heterogeneity test yields a significant result, $Q(5) = 0.01$, $p = 0.000$, indicating substantial variation among the included studies. This means the effect sizes are not homogeneous, and therefore, a random-effects model is more appropriate for interpreting the overall findings. Second, the pooled effect test yields $t(5) = 1.57$, $p = .176$, indicating that the combined effect across studies is not statistically significant. In other words, when the data from all studies are aggregated, the intervention (e.g., virtual reality-based learning) does not demonstrate a consistent or significant overall impact on the measured outcomes. These results suggest that although individual studies may demonstrate positive effects, the variability between them diminishes the overall strength of the conclusion.

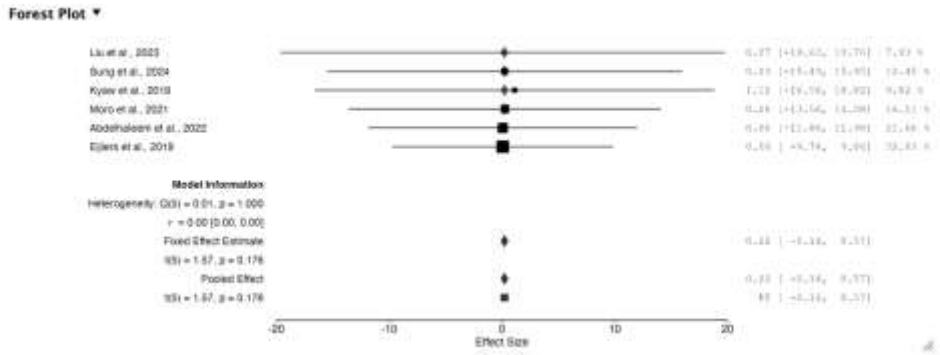
Table 4. Presents the meta-analytic estimates

Meta-Analytic Estimates ▼

		95% CI		95% PI	
	Estimate	Lower	Upper	Lower	Upper
Pooled effect	0.218	−0.138	0.573	−0.138	0.573
τ	0.000	0.000	0.000		
τ^2	0.000	0.000	0.000		

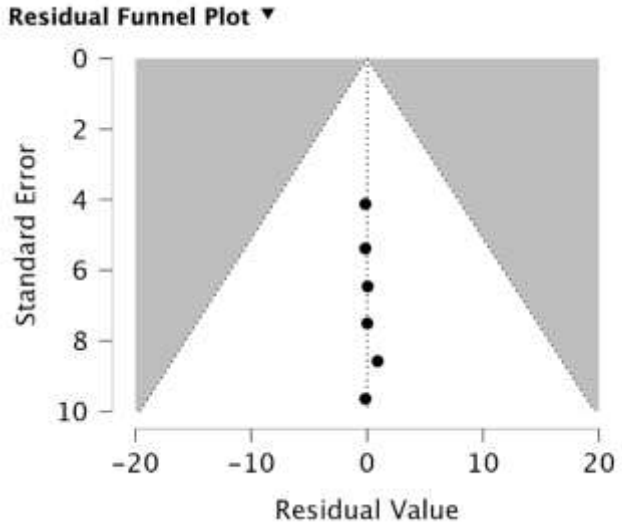
The table presents the meta-analytic estimates, showing a pooled effect size of 0.218 with a 95% confidence interval (CI) ranging from –0.138 to 0.573. The prediction interval (PI) shares the same range, suggesting consistent estimation across studies. The heterogeneity statistics τ (tau) and τ^2 (tau-squared) are 0.000, indicating no observed heterogeneity among the included studies. This implies that the effects across studies are highly consistent, and the overall pooled estimate represents a stable summary effect.

Figure 2. A forest plot illustrates



The forest plot illustrates the individual and pooled effect sizes from six studies included in the meta-analysis. Each horizontal line represents a study's confidence interval, while the squares indicate the effect size estimates, with their size reflecting study weight. The overall pooled effect, represented by a diamond at the bottom, shows an effect size of 0.22 (95% CI: –0.14 to 0.57). The heterogeneity statistics indicate $Q(5) = 0.01$, $p = 1.000$, and $I^2 = 0.00\%$, suggesting no significant heterogeneity among studies. This means the results are consistent and the variation between studies is negligible. The meta-analysis suggests a small but positive, non-significant pooled effect with stable inter-study consistency.

Figure 3. Residual funnel plot



The residual funnel plot illustrates the distribution of effect sizes from the included studies relative to their standard errors. The points (black dots) are symmetrically distributed around the central vertical line (representing the overall mean effect), indicating no substantial publication bias or systematic asymmetry in the data. The symmetry suggests smaller studies do not consistently report exaggerated effects, and the residual variation across studies appears random. However, because all points are located near the center with relatively large standard errors, the overall precision of the studies is low. In summary, the funnel plot supports the assumption of low publication bias but indicates limited statistical precision due to variability in sample sizes or study design.

Discussion

From the results The literature analysis presented reveals two complementary yet distinct domains of evidence: (1) strong quantitative evidence from the domains of health education and science extrapolated through several large meta-analyses (e.g., Liu et al., 2023; Sung et al., 2024; Kyaw et al., 2019; Moro et al., 2021), and (2) contextual and applied evidence derived from developmental studies and literature reviews in the context of pencak silat and physical education (e.g., Sampurna et al., 2021; Nelson et al., 2023; Rohayati et al., 2022; Da'i et al., 2024; (Sinulingga et al., 2023); Hardovi et al., 2025). Integrating these two sources enables richer insights into pencak silat learning practices and highlights the need for further research.

Based on the above evidence integration, it is recommended: (1) conduct RCTs or pseudo-experiments in a junior high school setting that measure objective outcomes (sensor-based motion capture, standardized teacher assessment), (2) measure skill transfer to practical contexts and medium-term retention, (3) incorporate affective and cultural outcomes (motivation, cultural identity), (4) conduct a cost-benefit analysis to assess school-scale feasibility, and (5) develop a reproducible VR content package accompanied by teacher training modules and learning analytics for personalized learning. Integrating meta-analytical evidence from the health field and applied evidence from pencak silat studies shows that VR is a technology with high potential to improve motivation, engagement, and cognitive aspects of learning. However, the claim of VR's effectiveness in transferring complex motor skills to real-world practice in the context of pencak silat still requires stronger experimental evidence. Future research

should adopt more rigorous experimental designs and objective measurement tools, and consider infrastructure readiness and cultural values when designing pedagogical approaches.

Limitations and Future Directions

While this systematic review and meta-analysis provide comprehensive evidence of VR's educational potential, several limitations should be acknowledged. First, the generalizability of the findings remains constrained because most included studies were conducted in medical and health education, with only a few addressing physical education or traditional martial arts such as Pencak Silat. Second, the heterogeneity of intervention types, devices (immersive vs. non-immersive), and outcome measures limits direct comparability across studies. Third, the absence of randomized controlled trials (RCTs) in the specific context of Pencak Silat education restricts the ability to draw causal conclusions about transferring motor skills from virtual to real-world performance. Future research should focus on conducting RCTs or quasi-experimental designs within junior high school settings, using objective performance assessments (e.g., motion tracking, expert evaluation), and integrating long-term retention measures. Additionally, future work should explore the integration of cultural identity and pedagogical frameworks into VR-based learning environments to preserve the philosophical essence of Pencak Silat while promoting technological innovation.

Novelty Statement (Contribution to Knowledge)

This study is the first systematic review and meta-analytic synthesis to integrate global evidence on virtual reality applications in education, specifically focusing on Pencak Silat, a traditional Indonesian martial art. The novelty lies in bridging technological pedagogy, motor learning theory, and cultural preservation, positioning VR as an instructional innovation and a medium for sustaining national heritage through digital transformation. By linking empirical meta-analytic findings with contextual thematic evidence, this review provides a conceptual and methodological foundation for future experimental research and the integration of VR in physical education curricula.

CONCLUSION

This systematic review and meta-analysis demonstrate that virtual reality (VR) has strong potential as an innovative medium in education, with consistent evidence supporting improvements in knowledge, cognitive skills, and affective aspects, including learning satisfaction and motivation. The meta-analysis results confirmed minor to moderate effects for knowledge and practical skills, as well as a significant impact on learning satisfaction and specific cognitive skills. However, the heterogeneity of interventions and methodological differences across studies still pose challenges in drawing strong generalizations. Furthermore, the specific literature on VR in physical education and pencak silat shows promising trends, although most research still focuses on media development, expert validation, and exploratory studies. While the findings of this study support the potential of VR to increase motivation, engagement, and fundamental understanding of pencak silat movements, empirical evidence assessing the transfer of complex motor skills to real-world practice remains limited. Therefore, this study concludes that VR is important in cognitively and affectively enriching the learning experience. However, its application to pencak silat learning is still in its early stages of development.

Further research is therefore needed, utilizing a quasi-experimental design or randomized controlled trials, objective measurement instruments, and the integration of cultural values, to optimize the effectiveness of VR in supporting physical education and preserving traditional martial arts in high schools.

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