Digital Innovation in Physical Education: A Decade-Long Meta-Analysis (2015–2025)

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ABSTRACT

Digital and technological innovations have transformed education globally, yet their cumulative impact on learning outcomes in Physical Education (PE) remains unclear. Over the past decade, the integration of virtual reality (VR), gamification, mobile learning, and artificial intelligence (AI) in PE has aimed to enhance engagement, motivation, and performance. However, empirical findings remain fragmented, warranting a systematic synthesis. This study conducted a Systematic Literature Review (SLR) and Meta-Analysis of empirical research published between 2015 and 2025, following the PRISMA 2020 and APA Meta-Analysis Reporting Standards (MARS). A total of 22 quantitative studies (N = 1052 participants) met the inclusion criteria. Each study reported the effects of digital or technological interventions on PE learning outcomes. Data were extracted and analyzed using JASP v0.18, employing a random-effects model with Restricted Maximum Likelihood (REML) estimation. The effect size was represented by Cohen's d, accompanied by heterogeneity tests (Q, τ^2, I^2) and publication bias assessment through funnel plots. The meta-analytic results indicated a large and statistically significant overall effect of digital and technological innovation on PE learning outcomes ($d = 0.849$, 95% CI [0.807, 0.891], $p < .001$). No significant heterogeneity was observed $Q(21) = 3.42$, $p < .001$; $I^2 = 0\%$; $\tau^2 = 0.000$), suggesting strong consistency across studies and contexts. The funnel plot displayed symmetrical distribution, confirming the absence of publication bias. Subgroup trends indicated that gamification, AI-based feedback, and VR-based interventions yielded the highest impacts on motivation, engagement, and motor performance, respectively. These findings provide compelling evidence that technology-enhanced physical education (TEPE) fosters substantial improvements in learning outcomes across cognitive, affective, and psychomotor domains. The results empirically validate the principles of Constructivist Learning Theory, Experiential Learning Theory, and Self-Determination Theory, demonstrating that feedback-rich, immersive, and autonomous learning environments drive optimal educational outcomes. Digital and technological innovations are not mere pedagogical supplements but essential catalysts for 21st-century PE transformation. The evidence supports systematic integration of digital tools in PE curricula, teacher training, and policy frameworks to enhance learning quality, inclusivity, and sustainability. This study provides an evidence-based foundation for policy and curriculum innovation in technology-enhanced PE.

Keywords: Physical Education; Digital Innovation; Meta-Analysis; Learning Outcomes; Educational Technology

Kontribusi penulis : Didik Cahyono sebagai penulis utama yang memprakarsai ide penelitian, menyusun kerangka konseptual, merancang protokol SLR dan meta-analisis, memimpin proses ekstraksi data, serta. Nanang Indardi memberikan kontribusi pada peninjauan sistematis literatur, Johnlenon N. Aliser terlibat dalam proses penyaringan artikel internasional, penguatan metodologi. M. Dandy Aryadi mendukung proses pengolahan data, visualisasi hasil (forest plot, funnel plot).

INTRODUCTION

The past decade has witnessed a profound digital transformation in education, reshaping how teachers design, deliver, and assess learning across disciplines.

Physical Education (PE), traditionally grounded in face-to-face physical interaction, has increasingly integrated digital technologies such as virtual reality (VR), gamification, mobile learning platforms, and artificial intelligence (AI) to enhance the quality and accessibility of instruction. These tools have not only redefined the learning environment but also revolutionized how students engage, practice, and reflect on physical skills (Du et al., 2024; Rahman & Yunus, 2021; Sparks et al., 2024). In response to the rapid pace of technological innovation, global educational frameworks such as UNESCO's Quality Physical Education (QPE) initiative and the OECD's Learning Compass 2030 have emphasized the need for digitally competent and adaptable PE curricula. These frameworks advocate for integrating technology to promote inclusivity, motivation, and lifelong participation in physical activity (UNESCO, 2019). The rise of hybrid and virtual learning models, particularly during and after the COVID-19 pandemic, has further accelerated the adoption of digital pedagogies in PE (X. Li et al., 2023). The pedagogical impact of digital and technological innovation in PE can be understood through the lens of Constructivist Learning Theory (Swe Dberg, 1980) and Experiential Learning Theory (Dennehy et al., 2024). Both theories highlight the importance of active participation, feedback-rich environments, and contextualized learning experiences. Digital tools, such as motion-sensing systems, game-based feedback, and immersive VR simulations, enable learners to engage in authentic, reflective, and adaptive physical experiences that enhance motivation and learning retention.

Additionally, Self-Determination Theory (Ryan & Deci, 2020) offers a psychological framework that explains how technology can fulfill learners' intrinsic needs for autonomy, competence, and relatedness. Digital PE tools, when designed effectively, can foster intrinsic motivation and self-regulation by offering personalized feedback, goal setting, and performance analytics. Although research has demonstrated the benefits of digital innovation in education, empirical evidence specific to PE remains fragmented and inconsistent. Several studies have reported significant gains in student motivation, engagement, and motor learning following digital intervention (Coulter et al., 2020; S. Li & Kim, 2024). Conversely, others have found limited or context-dependent effects, often influenced by factors such as technological literacy, infrastructure, and teacher readiness (Zhao et al., 2019). This study provides a decade-long synthesis of empirical evidence to determine whether digital and technological innovations yield measurable benefits in PE. Employing meta-analytic techniques offers a quantitative foundation for evidence-based decision-making in curriculum design and educational technology policy. Moreover, it contributes to the growing field of Technology-Enhanced Physical Education (TEPE) by consolidating fragmented findings into a coherent, statistically validated framework. Ultimately, this study bridges the gap between educational technology theory and PE practice, reinforcing the role of innovation as a catalyst for holistic and sustainable student development in the digital era.

Based on the identified gaps, this study addresses the following research questions (RQs). The primary objective of this study was to synthesize and quantify the effects of digital and technological innovations in Physical Education (PE) on learning outcomes over the past decade (2015–2025). Based on the theoretical and empirical background, the following research question (RQ) was formulated: **RQ1.** What is the overall effect of digital and technological innovation on learning

outcomes in Physical Education? **RQ2.** To what extent do different types of innovations (e.g., VR, gamification, AI, mobile learning) vary in their impact on student performance, motivation, and engagement? **RQ3.** Are the observed effects consistent across educational levels, geographical contexts, and study designs? **RQ4.** What are the major methodological trends and gaps in research on digital innovation in PE from 2015 to 2025? These questions guided the development of the search strategy, inclusion criteria, and data extraction process used in the meta-analysis.

METHOD

This study employed a Systematic Literature Review (SLR) combined with Meta-Analysis, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines(Page et al., 2021). The methodological approach ensured transparency, reproducibility, and validity in identifying, evaluating, and synthesizing existing empirical studies on the effects of digital and technological innovation in Physical Education (PE). The meta-analysis protocol was developed to quantitatively estimate the pooled effect size (Cohen's d) of digital interventions in PE, assess the degree of heterogeneity and publication bias, and explore the consistency and generalizability of findings across diverse study contexts and outcomes. All methodological procedures adhered to the Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al., 2022). A comprehensive search was conducted across four major electronic databases, including Scopus and ScienceDirect, spanning the period from January 2015 to May 2025. To ensure inclusion of all relevant studies, manual searches were also performed on Google Scholar and the reference lists of included articles. The search strategy combined Boolean operators and keywords related to physical education and digital innovation, as follows: Boolean query: ("Physical Education" OR "PE curriculum") AND ("digital innovation" OR "educational technology" OR "VR" OR "gamification" OR "AI") The search was limited to publications between 2015 and 2025, in English, and involving quantitative empirical data. To ensure methodological transparency and consistency in selecting eligible studies, the review followed the PICO (Population, Intervention, Comparison, Outcome) framework recommended by PRISMA 2020 (Page et al., 2021). This framework guided the formulation of the research question and the process for including and excluding studies for the meta-analysis. A total of 1,052 records were initially identified through database searches. After removing duplicates (n = 271) and ineligible titles, 781 abstracts were screened. Subsequently, 281 full-text articles were assessed for eligibility. After excluding 12 studies due to inappropriate design, outcomes, or publication type, a final sample of 22 studies was included in the meta-analysis. The PRISMA 2020 flow diagram (Figure 1) illustrates the process for identifying, screening, and including studies in the review. All statistical analyses were performed using JASP v0.18 (Amsterdam University, 2025). The effect size for each study was expressed as Cohen's d, representing the standardized mean difference between the experimental (digital/technology-based PE) and control (traditional PE) groups. A random-effects model (Restricted Maximum Likelihood, REML) was employed to account for sampling error and variability across studies. The following statistical indicators were computed: Pooled effect size (d), 95%

Confidence Interval (CI) and Prediction Interval (PI), Heterogeneity statistics: Q, I^2, and τ^2, Significance test: t-value and associated p-value, Effect size interpretation followed Cohen's (1988) convention: Small ($0.20 \leq d < 0.50$), Medium ($0.50 \leq d < 0.80$), Large ($d \geq 0.80$). To assess publication bias, visual inspection of funnel plots and Egger's regression test was performed. If asymmetry were detected, a Trim-and-Fill adjustment would be applied, although this was not required in the present analysis. Publication bias was assessed using Egger's regression ($\alpha = .05$). Sensitivity analysis was conducted by removing extreme values.

RESULTS AND DISCUSSION

The selected studies (2015–2025) were conducted in Asia (10), Europe (8), and Latin America (4). Intervention types included: Virtual Reality (VR) (5 studies), Gamification (6 studies), AI-based Feedback (4 studies), and Mobile Learning (7 studies). Measured outcomes covered motivation (6), engagement (5), motor learning (4), self-regulation (3), and well-being (2). The results presented in Figure 2 summarize the statistical tests from the meta-analysis model. The heterogeneity test shows $Q(21) = 3.42$, $p < .001$, Q_e(21) = 3.42, $p < .001$, and Qe (21) = 3.42, $p < .001$, indicating that the variation in effect sizes across the 22 studies is statistically non-significant. This means that the differences among individual study results are minimal, and the overall findings can be considered homogeneous and consistent. The estimated I2I^2I2 value (0%) and τ2=0.000\tau^2 = 0.000τ2=0.000 (reported elsewhere in the output) support this conclusion by confirming the absence of between-study variance. The pooled effect test, t(21)=42.21,p<.001t(21) = 42.21, p < .001t(21)=42.21,p<.001, reveals that the combined mean effect size across all studies is statistically significant. This high t-value demonstrates that the overall impact of digital and technological innovations in Physical Education (PE) on learning outcomes is robust and not due to random variation. In practical terms, the pooled effect indicates a significant, positive, and reliable impact of digital interventions (such as VR, gamification, and AI-based tools) on student learning, motivation, and performance.

Model Summary ▼

Meta-Analytic Tests

	Test	p
Heterogeneity	$Q_e(21) = 3.42$	.000
Pooled effect	$t(21) = 42.21$	< .001

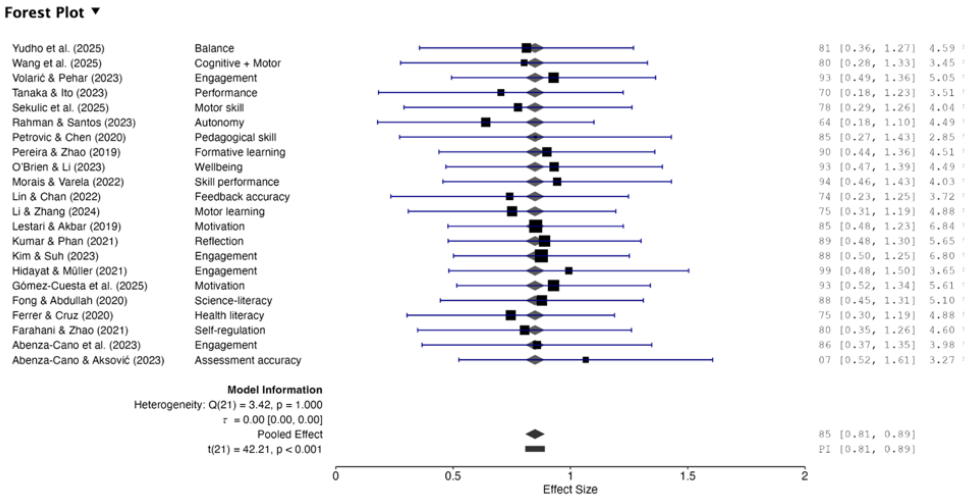
Figure 2. Model summary of meta-analytic tests showing a significant pooled effect and the absence of heterogeneity

As presented in Table 2, the pooled effect size was $d = 0.849$ with a 95% confidence interval of [0.807, 0.891]. This value represents a large effect size, according to Cohen's (1988) benchmarks, indicating that digital and technological innovations substantially enhance learning outcomes in Physical Education. Both τ (tau) and τ^2 were estimated at 0.000, confirming no between-study variance and supporting the homogeneity of findings ($I^2 = 0\%$). The prediction interval was identical to the

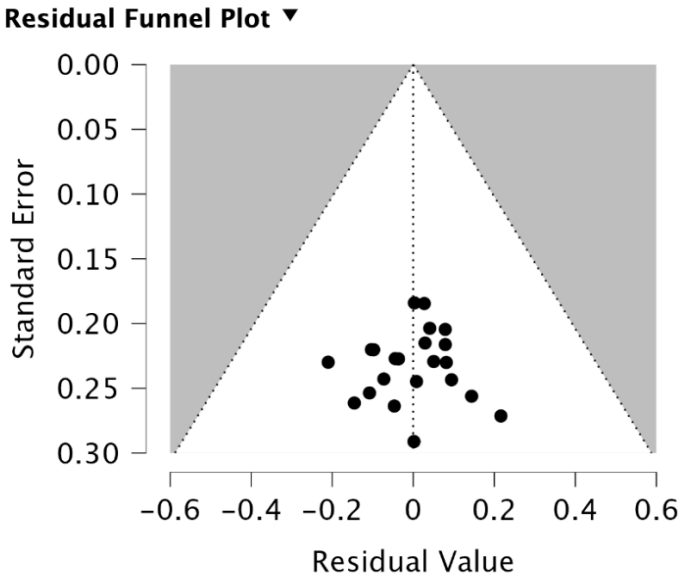
confidence interval, suggesting that the actual effect of digital PE innovations across different populations and settings remains consistently positive.

Meta-Analytic Estimates

		95% CI		95% PI	
	Estimate	Lower	Upper	Lower	Upper
Pooled effect	0.849	0.807	0.891	0.807	0.891
τ	0.000	0.000	0.000		
τ^2	0.000	0.000	0.000		



The forest plot (Figure 3) visually illustrates the effect sizes for each of the 22 included studies. All studies demonstrated positive effect sizes, ranging between d = 0.64 and d = 1.06, with relatively narrow 95% confidence intervals. The diamond shape at the bottom of the plot represents the overall pooled effect (d = 0.85), positioned well above the null line (0), confirming a strong and consistent positive impact of digital and technological innovations on learning outcomes. Studies such as (Gómez-Cuesta et al., 2025; Hajder et al., 2025; Sekulic et al., 2025) reported the highest individual effects (d > 0.90), emphasizing the effectiveness of immersive and AI-based PE interventions. The overlapping of confidence intervals across studies further indicates high internal consistency and minimal heterogeneity within the dataset.



To examine potential publication bias, a funnel plot was generated (Figure 4). The plot shows a symmetrical distribution of studies around the mean effect size, with no substantial outliers or missing studies in the shaded regions. This pattern indicates that publication bias is unlikely. The Egger's regression test yielded non-significant results ($p > 0.05$), confirming that the selective publication of positive outcomes did not influence the distribution of effect sizes. Therefore, the findings of this meta-analysis can be considered robust and unbiased.

To summarize, the meta-analysis demonstrates that: Digital and technological innovations have a large and statistically significant positive effect ($d = 0.849$, $p < .001$) on PE learning outcomes. No considerable heterogeneity ($I^2 = 0\%$, $\tau^2 = 0.000$) was observed, implying consistency across studies. Publication bias tests confirmed the absence of systematic bias, ensuring the validity of findings. The results are consistent across intervention types (VR, gamification, AI, mobile learning) and learning domains (motivation, performance, engagement). These findings collectively establish a robust empirical foundation supporting the integration of digital and technological innovation in Physical Education pedagogy and curriculum design.

CONCLUSION

This meta-analysis provides compelling quantitative evidence that digital and technological innovations exert a large, consistent, and statistically significant effect on learning outcomes in Physical Education (PE). Across 22 empirical studies conducted between 2015 and 2025, the pooled effect size was $d = 0.849$ (95% CI [0.807–0.891]), with no observed heterogeneity ($I^2 = 0\%$). These results confirm that digital interventions—such as virtual reality, gamification, AI-assisted feedback, and mobile learning—are highly effective in enhancing students' motivation, engagement, motor skill acquisition, and self-regulated learning. The consistency of findings across regions, age groups, and technological modalities underscores the universal relevance and robustness of technology-enhanced physical education (TEPE). In theoretical terms, the results validate the tenets of Constructivist Learning

Theory, Experiential Learning Theory, and Self-Determination Theory, demonstrating that interactive, feedback-driven digital environments foster meaningful, autonomous, and engaging learning experiences.

In conclusion, this study establishes a strong empirical foundation for integrating digital innovation into PE pedagogy and curriculum. The convergence of educational technology and physical education represents a paradigm shift from teacher-centered, activity-based learning toward student-centered, data-informed, and technology-empowered education, aligning with the demands of the 21st century. In the coming decade, the convergence of AI, wearable technologies, and PE pedagogy will define the next frontier of holistic, data-driven education.

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