



Integrating Technology in PE: A Scoping Review of Drone Soccer as a Catalyst for Student Skill Development and Ethical Awareness

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ABSTRACT

Purpose of the study: This study investigates drone soccer's potential as a pedagogical tool for integrating technology within physical education (PE). It bridges traditional athletics and STEM-oriented motor skills, exploring how this sport facilitates the dual-track development of technical proficiency and ethical responsibility in K-12 and higher education.

Methodology: Guided by the updated PRISMA guidelines, this scoping review comprehensively synthesizes 35 key studies from multidisciplinary databases. It utilizes the I-TPACK and SAMR models to assess the depth of technology integration. Furthermore, reflexive thematic analysis (RTA) evaluates drone soccer's pedagogical and ethical efficacy across psychomotor, cognitive, and social-emotional domains.

Main Findings: The analysis suggests that drone soccer functions as a significant catalyst for enhancing visual-motor integration (VMI), fine motor dexterity, and collaborative problem-solving. Beyond physical benefits, the sport provides a structured environment for instilling "technological ethics," promoting fair play, privacy awareness, and responsible tech usage. Applying the SAMR model reveals that drone soccer allows for a "redefinition" of PE activities, transforming conventional sports into high-level, interdisciplinary learning experiences that dissolve the boundaries between physical activity and digital engineering.

Novelty/Originality of this study: This paper offers a pioneering perspective by positioning drone soccer at the intersection of competitive robotics and physical education. Unlike traditional technology integration studies that focus on exergaming or wearables, it uniquely identifies drone soccer as a holistic vehicle for both advanced motor skills and ethical consciousness, providing a validated theoretical roadmap for future technology-enhanced PE curricula.

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1. INTRODUCTION

Physical Education is an integral component of the holistic educational process. It aims to cultivate physically, mentally, emotionally, and socially well-rounded individuals through carefully selected physical activities [1], [2]. By emphasizing "education through the physical," PE leverages gross motor movements to elicit positive transformations in both physical functioning and social behavior. PE scene is radically changing, with fast improvements in technology, and the increased awareness of the necessity of more inclusive, engaging, and skills-related pedagogy practices. PE as a component of the K-12 curriculum has, over the decades, been a foundation

of healthy lifestyles, development of motor skills and physical fitness. Nevertheless, conventional PE has been criticized on multiple occasions as adopting a one-size-fits-all model, focusing on competitive sports excessively and not being able to attract students with different backgrounds. This mechanistic approach fails to promote social processes where decision-making and collaborative problem-solving are valued [3], [4]. To overcome these limitations, Digital-Intelligent Technologies (DIT), which stand at the convergence of artificial intelligence and digital transformation, have become pivotal to the modernization of PE [5]-[7]. Due to these demands, educators and researchers nowadays tend to rely more on technology as a way of rejuvenating the PE curriculum, creating a more inclusive and student-focused learning process and providing students with 21st-century skills.

The paper under consideration examines how PE should integrate technology with references to a rather innovative and potentially effective new activity: drone soccer. Drone soccer is a sporting product, a fast, team-based competition game in which students will construct, code and fly small encased drones to compete against each other. It is a combination of fun like a video game and hands-on learning like a robotics project and provides a distinct and intriguing method of imparting a vast variety of skills. To study the potential of the technology to revolutionize PE, including improving student engagement, motivation, as well as developing the crucial cognitive, motor, and social-emotional abilities, drone soccer, as a case study, offers an abundant context to explore the potential of technology in redefining PE. The main thesis of the present paper is that drone soccer as an instrument when introduced with proper planning and ethical considerations can be an efficient tool towards fostering the growth of skills and moral understanding in students when applied to PE.

In particular, this paper explores how drone soccer can be applied to promote multiple developmental facets simultaneously. The highly collaborative nature of the game requires students to cooperate toward shared objectives, fostering essential teamwork and distributed leadership. Simultaneously, piloting the drones demands accurate visual-motor integration and rapid eye-hand coordination. Beyond physical skills, the competitive yet structured environment naturally cultivates social-emotional learning (SEL) competencies, such as emotional regulation and responsible decision-making. Furthermore, it serves as an authentic vehicle for interdisciplinary STEM integration and prompts critical discussions regarding ethical awareness and the responsible use of autonomous systems

While Digital-Intelligent Technologies (DIT) are increasingly applied in education [5], a fundamental gap remains regarding "what the scientific world does not yet know" about the systematic integration of competitive robotics within Physical Education (PE). First, the precise pedagogical mechanisms by which high-speed, multi-sensory tasks such as First-Person View (FPV) drone piloting translate into traditional gross motor skills and physical coordination remain empirically unverified. While prior research highlights the transferability of virtual exergaming to physical outcomes [8], it remains unknown how the simultaneous cognitive load of navigating a drone in a dynamic, 3D physical space affects students' visual-motor integration compared to conventional sports. Second, although interactive robotics are prevalent in structured STEM classrooms [9], [10], the scientific community lacks an evidence-based ethical and pedagogical framework tailored to the unpredictable, high-contact environment of drone sports. It remains largely unexplored how the dual demands of technical drone operation and physical team coordination uniquely influence social-emotional learning (SEL) in a competitive PE context [11].

This research is urgent as traditional, "one-size-fits-all" PE models often fail to engage digitally native students [3], [4]. Given the ubiquity of autonomous systems, there is an immediate pedagogical necessity to move beyond mere physical activity toward a framework that manages the cognitive-motor synergy required by interactive robotics. Without such an evidence-based roadmap, drone soccer risks being implemented as a transient novelty rather than a transformative tool that bridges the divide between physical prowess and digital engineering [12]-[14].

Therefore, this study is structured as a scoping review. The primary research objective is to map the multidisciplinary literature and evaluate the pedagogical and ethical efficacy of drone soccer in physical education. Specifically, this review addresses two main research questions: (1) How does drone soccer facilitate the acquisition of psychomotor, cognitive, and social-emotional skills in students? (2) What ethical frameworks are necessary to guide the responsible integration of such emerging technologies in physical education?

2. THE COMPREHENSIVE THEORETICAL BASIS

2.1. Critical Synthesis of Technology Integration Frameworks

Rather than functioning merely as descriptive concepts, the TPACK and SAMR models must be critically examined regarding their practical application in physical education. While the original TPACK framework Mishra & Koehler [15] provided a foundation for integrating digital tools, a critical synthesis of recent literature reveals that its application in PE frequently stagnates. Teachers often focus on basic Technological Knowledge (TK) without achieving a deep integration with Pedagogical Content Knowledge (PCK) [16]-[18]. Similarly, when viewed through the SAMR model [19], technology in PE typically plateaus at the "Substitution" or

"Augmentation" tiers (e.g., using digital stopwatches or basic heart rate monitors) rather than reaching the transformative "Modification" or "Redefinition" stages [20]. To overcome these limitations and handle the complexity of autonomous systems, recent studies advocate for the Intelligent-TPACK (I-TPACK) framework [21]-[23]. This review utilizes I-TPACK alongside SAMR to critically evaluate how drone soccer pushes PE beyond basic augmentation, demanding a redefinition of pedagogy that intertwines ethical responsibility with advanced technical and physical coordination.

2.2. Comparative Analysis of Technology and Robotics in PE Pedagogy

A comparative analysis of recent technological interventions in PE reveals a distinct pedagogical dichotomy. On one hand, traditional PE technologies, such as pedometers, wearables, and VR exergaming, have successfully increased physical activity levels and physiological monitoring [24], [25]. However, these tools primarily track or gamify physical exertion without fostering high-level engineering or STEM skills. On the other hand, educational robotics and unmanned aerial vehicles (UAVs) introduce significant cognitive and micro-motor challenges. Meta-analyses and reviews confirm that robotics and drones significantly enhance STEM problem-solving, spatial visualization, and student motivation [9], [10], [26].

Drones explicitly bridge theoretical STEM concepts with practical application [27], [28], positively influencing sequencing skills and mathematical understanding [29]-[31]. Yet, a critical comparison highlights a persistent gap: while robotics like the NAO or LEGO platforms have been used to support PE and STEM separately (e.g., improving attention spans) [32], there is a lack of integration combining vigorous team-based physical competition with advanced robotics control. Drones used purely in STEM often lack the gross motor and collaborative physical components of traditional sports, while PE wearables lack cognitive STEM engagement.

2.3. Positioning of the Current Review

Existing literature predominantly treats technology in PE either as a biometric tracking tool or a passive gamified distraction. There is a distinct lack of synthesis comparing traditional physical exertion with the cognitive and ethical demands of competitive robotics. This scoping review explicitly addresses this void. It positions drone soccer not merely as an alternative physical activity, but as a dual-track pedagogical catalyst. By synthesizing literature across these disparate fields, this study demonstrates how drone soccer bridges the gap between passive STEM robotics and purely physical PE, uniquely redefining psychomotor skill acquisition and digital citizenship within the I-TPACK framework.

3. RESEARCH METHOD

3.1. Literature Selection and Synthesis

This study is designed as a scoping review to map the broad conceptual landscape of drone technology integration in PE. The literature synthesis was conducted by systematically searching multidisciplinary databases, including Web of Science, Scopus, and Google Scholar, as well as official educational policy repositories. Sources were selected based on their relevance to STEM education and physical education pedagogy from 2020 to 2024. To ensure high reporting transparency and methodological rigor, the literature search and selection process strictly adhered to the updated PRISMA 2020 guidelines [34].

3.1.1. Search Strategy and Data Sources

To capture the multidisciplinary nature of the topic, a comprehensive systematic search was conducted across four primary electronic databases: Web of Science (Core Collection), Scopus, PubMed, and Google Scholar. The search was restricted to publications between January 2020 and December 2024 to ensure relevance to current technological advancements. The Boolean search string was constructed combining three conceptual blocks: (1) Technology Context: ("drone soccer" OR "educational robotics" OR "unmanned aircraft systems" OR "educational drones") AND (2) Pedagogical Context: ("physical education" OR "PE" OR "STEM integration" OR "K-12 curriculum") AND (3) Target Outcomes: ("skill development" OR "visual-motor integration" OR "social-emotional learning" OR "ethical awareness" OR "digital citizenship").

3.1.2. Eligibility Criteria

To ensure the rigor of the synthesized literature, strict eligibility criteria were applied: Inclusion Criteria: (1) Peer-reviewed journal articles, conference proceedings, and validated scoping/systematic reviews; (2) Studies explicitly examining the pedagogical use of drones or interactive robotics in educational settings; (3) Research reporting outcomes related to psychomotor skill acquisition, STEM integration, or ethical/digital citizenship development; (4) Published in English between 2020 and 2024. (Note: Purely methodological, conceptual frameworks such as SAMR or TPACK, and general policy documents cited for contextual grounding were excluded from the final PRISMA count of synthesized core studies). Exclusion Criteria: (1) Purely technical

engineering papers focused on drone manufacturing without educational applications; (2) Studies focusing exclusively on military, agricultural, or commercial drone deployment; (3) Non-peer-reviewed sources or incomplete abstracts lacking empirical data.

3.1.3. Screening Process and PRISMA-ScR Flow

The literature screening process strictly adhered to the PRISMA-ScR guidelines.

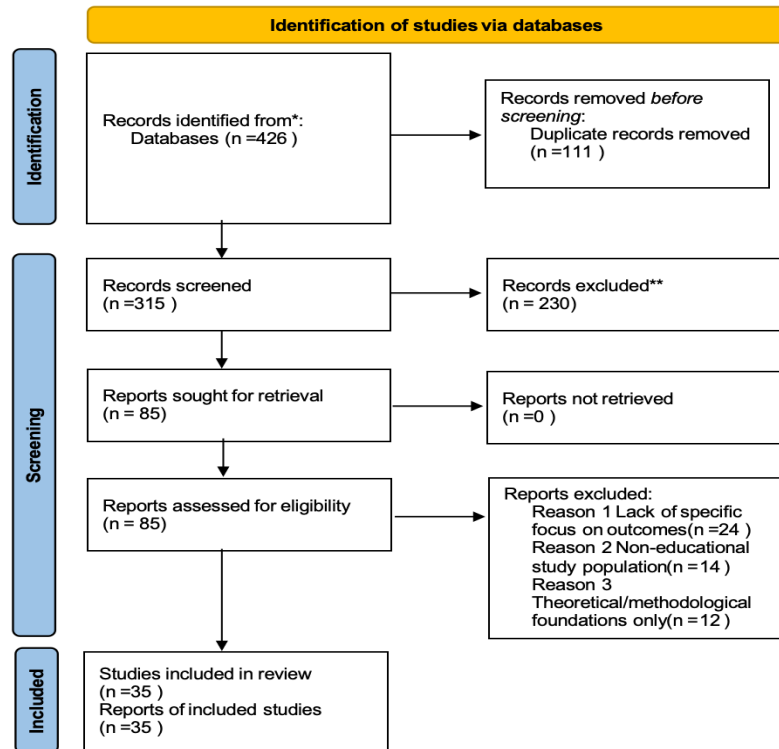


Figure 2. PRISMA-ScR Flow

The initial comprehensive database search yielded a total of 426 potential records. After removing 111 duplicate entries using reference management software, 315 unique records underwent Title and Abstract screening. During this initial screening phase, 230 records were excluded as they did not align with the educational or ethical context of the study (e.g., focusing solely on industrial drone applications or general aviation without pedagogical elements). The remaining 85 full-text articles were rigorously assessed for eligibility against the predefined criteria. Of these, 50 articles were excluded for the following reasons: lack of specific focus on psychomotor or ethical outcomes in student populations ($n=24$), non-educational study population ($n=14$), and articles serving merely as theoretical/methodological foundations rather than primary evaluative studies ($n=12$). Consequently, a final meticulously curated pool of 35 key studies was included in the thematic synthesis.

Literature Screening and Bias Management: To mitigate selection bias, the title, abstract, and full-text screening processes were conducted independently by two reviewers (F.W. and Z.Q.). A double-blind screening protocol was enforced using reference management software. Any discrepancies regarding study eligibility were resolved through critical discussion. If consensus could not be reached, the third senior reviewer (W.W.) acted as the final adjudicator, ensuring objective and consistent application of the inclusion criteria.

3.1.4. Quality Appraisal

To enhance the credibility of the synthesized results and meet high-impact journal standards, the methodological quality of the included 35 studies was critically appraised using the Mixed Methods Appraisal Tool (MMAT), version 2018 [35]. Two reviewers (F.W. and Z.Q.) independently assessed the studies based on methodological appropriateness, data adequacy, and risk of bias. Studies were not excluded solely based on quality scores to ensure a comprehensive scoping map; however, the appraisal results were actively utilized to weigh the strength of the evidence during the thematic synthesis.

3.2. Theoretical Framework Application

To ensure theoretical rigor, this study specifically builds upon the SAMR model proposed by Puentedura [19] to evaluate the hierarchical levels of technology integration. These frameworks were applied to evaluate how drone soccer transforms traditional PE activities into high-level technology-integrated learning experiences.

3.3. Thematic and Empirical Analysis

To ensure the reliability and transparency of the qualitative interpretations, the literature synthesis followed the six-phase Reflexive Thematic Analysis (RTA) approach developed by Braun and Clarke [36], [37]. As noted by the reviewers, evaluating the integration of complex technologies like drone soccer inherently involves pedagogical pre-assumptions. Therefore, to ensure transparency, we explicitly acknowledge that our initial coding adopted a hybrid approach: it was partially deductive, guided by established learning domains (psychomotor, cognitive, and social-emotional) and the TPACK framework [15], and partially inductive, allowing specific operational requirements and impacts of drone soccer to emerge directly from the extracted literature data.

The RTA process was operationalized through the following steps:

1. Familiarization and Data Extraction: The research team immersed themselves in the selected 35 key studies, extracting textual data related to technological implementation, pedagogical outcomes, and student skill acquisition.
2. Initial Code Generation: Meaningful segments of text were tagged with descriptive initial codes. For instance, findings related to "220 ms response latency" or "hand-eye coordination" were coded under precise physiological/cognitive markers.
3. Constructing Sub-themes: Initial codes with shared meanings were collated into broader sub-themes (e.g., merging "emotional regulation" and "joint attention" into "Emotional Resilience").
4. Defining Final Themes: The sub-themes were recursively reviewed against the dataset and the study's core objectives to generate the four definitive themes.

The complete coding framework, demonstrating the progression from initial data-driven codes to the final conceptual themes, is detailed in Table 1 below.

Coding Validation and Reliability:

To ensure the reliability of the coding process and mitigate individual subjectivity, investigator triangulation was employed [38]. Initial codes generated by the primary coder (F.W.) were systematically cross-examined by the co-authors (Z.Q. and W.W.). Disagreements in theme conceptualization were iteratively refined through collaborative discussions until team consensus was achieved, ensuring high methodological rigor in the reflexive thematic analysis.

Table 1. Reflexive Thematic Analysis (RTA) Coding Framework

Initial Codes (Extracted from Data)	Sub-themes (Collated Meanings)	Final Themes (Defined Categories)
<ul style="list-style-type: none"> • Reaction time & visual-motor response latency (e.g., 220 ms) • Hand-eye coordination & fine motor dexterity • Spatial anticipation & perception-action coupling • Eye-tracking metrics in FPV flight 	Visual-Motor Coordination & Spatial Visualization	Theme 1: Perceptual-Motor and Spatial-Cognitive Skills
<ul style="list-style-type: none"> • Emotional regulation during drone repair • Joint attention and peer empathy • Coping with negative emotions & resilience • Distributed leadership & role coordination 	Emotional Resilience & Collaborative Dynamics	Theme 2: Social-Emotional Learning (SEL) and Collaboration
<ul style="list-style-type: none"> • Application of geometry/trigonometry to flight paths • Game-based programming sequencing • Positive attitudes toward science and math • Active problem-solving in engineering contexts 	Applied STEM Concepts & Academic Engagement	Theme 3: Interdisciplinary STEM Integration
<ul style="list-style-type: none"> • FAA regulatory compliance & safety protocols • Informed consent and privacy awareness • Mitigating cyberbullying through digital citizenship • Responsible interactions with autonomous systems 	Regulatory Compliance & Responsible Tech Usage	Theme 4: Ethical Awareness and Digital Citizenship

4. RESULTS AND DISCUSSION

4.1. Synthesis of Included Studies and Theme Generation

Following the Reflexive Thematic Analysis (RTA) process of the 35 included studies, the synthesized literature yielded four primary themes regarding the integration of robotics and drones in educational settings. While the full conceptual synthesis encompasses all 35 records, a focused breakdown of the core empirical studies directly driving these themes reveals specific concentrations:

Theme 1: Perceptual-Motor and Spatial-Cognitive Skills: Focuses on visual-motor integration (VMI) and reaction metrics.

Theme 2: Social-Emotional Learning (SEL) and Collaboration: Examines emotional regulation, joint attention, and team-based problem-solving.

Theme 3: Interdisciplinary STEM Integration: Evaluates the broader academic impact and engagement levels in STEM subjects.

Theme 4: Ethical Awareness and Digital Citizenship: Addresses data privacy, safety, and responsible technology usage protocols.

Table 2. Summary of core studies synthesized for thematic generation

Author (Year)	Objective	Methodology	Key Findings	Themes Identified
Chin et al. (2024) [9]	To evaluate the effects of educational robotics on STEM learning outcomes.	Multilevel Meta-analysis (21 studies)	Identified a significantly positive overall effect on learning performance and attitudes, particularly through game-based strategies.	Interdisciplinary STEM Integration
Alotaibi et al. (2024) Error! Reference source not found.	To map the utilization and pedagogical impact of drones in educational environments.	Scoping Review	Drones significantly increase engagement and active learning, frequently elevating instructional design to the Modification and Redefinition tiers of SAMR.	Interdisciplinary STEM Integration
Khatib et al. (2022) [39]	To examine the relationship between visuomotor integration and academic achievement across educational stages.	Meta-analysis	Found that visuomotor integration significantly correlates with mathematics, reading, and overall academic achievement, highlighting the importance of cognitive-motor skills in child development.	Perceptual-Motor & Spatial Skills
Pfeiffer et al. (2021) [40]	To analyze visual processing and control mechanisms in human-piloted drone racing.	Empirical Study (Eye-tracking)	Indicated intense perception-action coupling, with pilots exhibiting an average visual-motor response latency of merely 220 ms.	Perceptual-Motor & Spatial Skills
De Brouwer et al. (2021) [41]	To explore the functional use of eye movements within active neuro-robotic systems.	Literature Review	Suggested that integrating visual-motor performance with robotic interaction enhances the overall efficiency of spatial anticipation.	Perceptual-Motor & Spatial Skills
Kewalramani et al. (2024) [42]	To review the use of robotics technologies for supporting social-emotional learning.	Scoping Review	Reported that interactive robotics actively support SEL by fostering emotional recognition, joint attention, and collaborative behaviors.	SEL & Collaboration
Leite et al. (2014) [43]	To assess the impact of long-term empathic interactions with social robots.	Empirical Study	Showed that interactions with robotic systems help youth regulate negative emotions and build resilience during iterative tasks.	SEL & Collaboration

Author (Year)	Objective	Methodology	Key Findings	Themes Identified
Karayol et al. (2025) [12]	To investigate the correlation between digital citizenship levels and cyberbullying attitudes.	Empirical Study	Provided empirical evidence that high digital citizenship levels act as a significant protective factor against negative digital behaviors.	Ethical Awareness & Citizenship
Hoek Spaans et al. (2024) [13]	To map ethical considerations related to drone use for environmental and health operations.	Review Protocol	Highlighted that establishing clear ethical protocols and securing informed consent are strictly essential for responsible implementation.	Ethical Awareness & Citizenship

Note: Table 2 below presents a representative subset of the most critical empirical studies that provided the foundational data for thematic generation. The remaining synthesized literature supports these core findings by providing broader methodological and contextual grounding.

Furthermore, an analysis of consistency and contradiction patterns across the included studies reveals strong consensus regarding the positive impacts of drone soccer on student engagement and spatial-cognitive skills. However, minor contextual contradictions were observed regarding the optimal implementation age, with some studies suggesting earlier exposure, indicating a need for age-stratified pedagogical frameworks in future curriculum design.

4.2. Drone Soccer: An Illustrative Case of Next-Generation PE Pedagogy

4.2.1. What is Drone Soccer?

Drone soccer is a full contact inter-team game involving small and encased drones on an indoor field, as shown in Figure 2. A game normally involves two teams of five players, each group of which has piloted a drone. The game aims at achieving the points by flying the drone through the opponents goal. The drones are protected in a bubble where they are able to hit one another without damaging them.

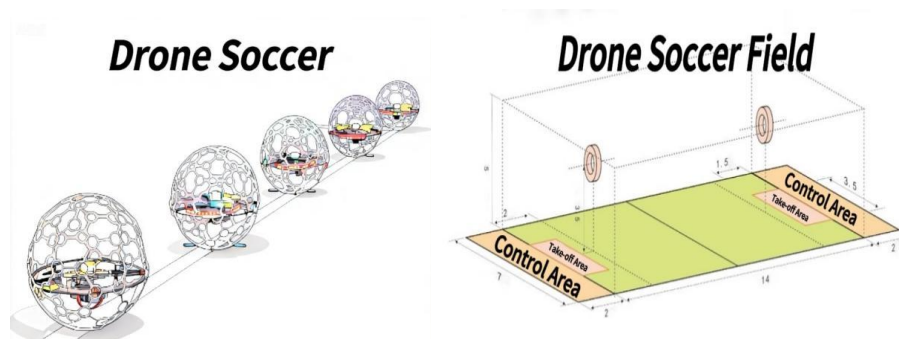


Figure 2. Schematic Overview of a Drone Soccer

4.2.2. The Educational Rationale for Drone Soccer

The pedagogical justification of drone soccer is based on three foundations: learning by construction, learning by competition, and learning by context.

4.2.3. Evidence Base for Drone Soccer

A 2024 multilevel meta-analysis of studies in the field of educational robotics established a significant positive effect on the overall performance and attitude to learning [9]. Systematic and scoping reviews of drones in education also suggest that unmanned aircraft systems (UAS) alter the experiences in the classroom on both the Modification and Redefinition tiers in the SAMR framework [10].

4.2.4. Programs and Case Studies

The U.S. Drone Soccer Association organizes national drone soccer competitions while promoting STEM-oriented educational programs that integrate engineering design, collaboration, coding, and applied science competencies aligned with NGSS-oriented learning practices [44]. The program indicates more than 270 institutions are participating and a growing championship footprint as of 2024-2025. EdTech Magazine also

reported in November 2024 that over 240 schools in the U.S. had implemented drone soccer, driven by the search for high-benefit STEM activities [45].

4.3. A Multi-Dimensional Analysis of Skill Development

4.3.1. Fostering Collaboration, Communication, and Shared Leadership

Drone soccer is fundamentally a team-based activity requiring clearly differentiated roles, tactical communication, real-time coordination, and collaborative decision-making to achieve competitive performance, [44], [46]. Furthermore, drone soccer promotes a model of distributed leadership [47]. This allows students to practice both leading and following, enhancing their situational awareness and emotional intelligence a dynamic supported by research on collaborative learning groups. This dynamic leverages collective intelligence, and recent studies in complex school and educational settings suggest that adaptive, distributed leadership practices are vital for sustaining a highly collaborative and innovation-oriented environment [48].

4.3.2. Enhancing Perceptual-Motor and Spatial-Cognitive Skills

Piloting a drone requires the real-time integration of visual information into precise motor commands, offering valuable training in visual-motor integration (VMI). This cognitive-motor skill is a significant predictor of academic achievement [39]. A recent meta-analysis identifies VMI as a key motor correlate of mathematical performance [49], [50]. During FPV (first-person view) flight, eye-tracking research shows that drone racing pilots exhibit an average visual-motor response latency of merely 220 ms, indicating intense perception-action coupling [41]. Clinical evaluations, frequently utilizing the Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery VMI), have consistently shown that robust motor coordination and spatial perception correlate strongly with higher writing legibility and mathematical abilities [51]-[53]. Furthermore, neuro-robotic studies suggest that integrating visual-motor performance with robotic interaction enhances the overall efficiency of the acting system and spatial anticipation [41].

Critical Analysis and Comparison: While studies like Pfeiffer et al. [40] highlight intense perception-action coupling, a critical comparison with general PE technology interventions reveals a pedagogical tension. Traditional wearable technologies primarily track and encourage gross motor exertion and physical activity (PA) outcomes [24]. In contrast, drone piloting focuses intensely on micro-motor dexterity and cognitive spatial anticipation [41]. Therefore, relying solely on drone soccer could risk reducing students' overall moderate-to-vigorous physical activity. To avoid this contradictory outcome, the literature implies that drone soccer must not completely replace traditional athletics but be integrated carefully to balance cardiovascular fitness with high-level visual-motor integration.

4.3.3. Promoting Social-Emotional Learning Competencies

The immersive and team-oriented context of drone soccer provides a practical platform for developing core Social-Emotional Learning competencies. Research in educational robotics suggests that hands-on robotics projects foster self-regulation, persistence, and emotional management through iterative problem-solving, debugging, and trial-and-error processes [54]. A scoping review of interactive robotics reports that these technologies actively support SEL by fostering emotional recognition, joint attention, and positive collaborative behaviors among students [42]. The structured integration of interactive tools, such as digital games and robotic companions, significantly impacts the development of empathy and interpersonal skills [55]-[57]. Specifically, long-term empathic interactions with social robotics have been shown to help youth regulate negative emotions and build resilience during challenging, iterative tasks [43], [58].

Contradictory Results and Implementation Barriers: Although evidence supports the development of empathy and resilience through robotics [42], [43], the broader literature also points to significant constraints. The complexity of drone technology can act as a barrier to social-emotional learning if educators face prohibitive technological challenges or lack instructional support [24]. Based on the COM-B behavior change framework Michie et al. [59], if students or teachers lack the specific capability or opportunity to manage technical failures, the activity may generate frustration rather than empathy. This highlights a critical contradiction: the SEL benefits observed by Kewalramani et al. [42] are highly dependent on structured pedagogical mediation, rather than being an automatic byproduct of the technology itself.

4.3.4. Facilitating Interdisciplinary STEM Integration and Systems Thinking

Drone soccer acts as a powerful integrator of STEM disciplines, moving beyond siloed subject teaching to authentic, applied learning. Mathematics is applied in geometry, trigonometry, and data analysis. This aligns with broader evidence showing that game-based and project-based robotics interventions positively impact STEM learning performance and attitudes [9].

Synthesis and Critical Discussion: A critical synthesis of the literature shows a clear divergence in educational approaches. Drone interventions are frequently utilized to redesign learning at the Modification and

Redefinition tiers of the SAMR model for STEM outcomes [10]. This contrasts sharply with the mechanistic, "one-size-fits-all" approach of traditional PE that often fails to engage diverse student populations [3], [4]. However, seamlessly integrating such advanced engineering concepts into PE requires significant curricular redesign. The literature emphasizes that explicitly bridging the gap between theoretical STEM knowledge and practical skill acquisition [27] demands rigorous teacher preparation to overcome institutional friction.

4.4. Navigating the Ethical Dimension: Towards Responsible Implementation

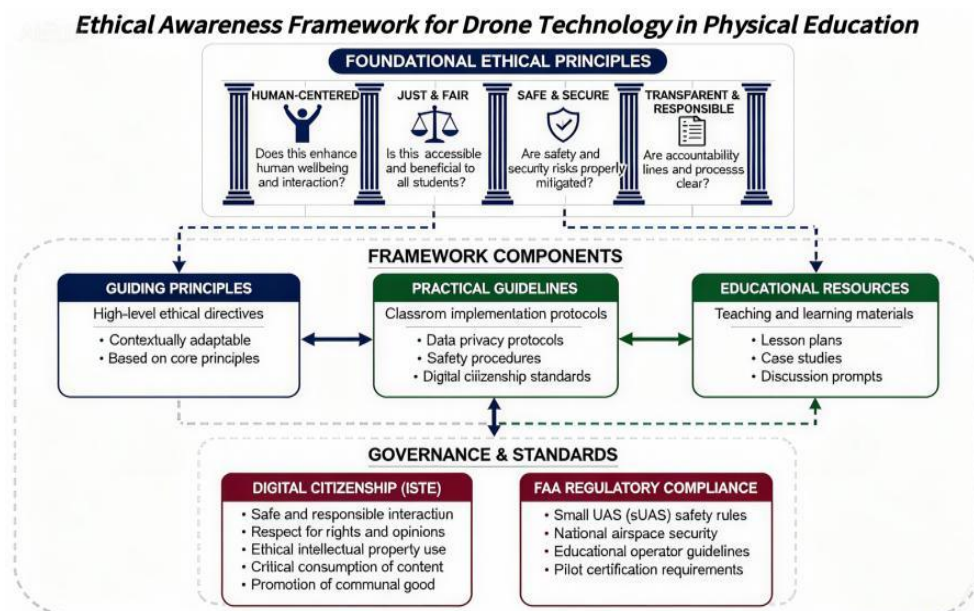


Figure 3. A Framework for Ethical Awareness and Responsible Technology Use in PE

The ethical framework will assist teachers and learners to overcome contradictory issues. The model is premised on four principles: Human-Centered, Just and Fair, Safe and Secure, and Transparent and Responsible. By the 2020s, digital citizenship has become an essential element of any ethical model of using technology in education. True digital citizenship is defined by the norms of appropriate, responsible, and empowered technology use, actively participating in online and offline communities [60], [61]. Empirical evidence suggests that cultivating high digital citizenship levels among prospective PE teachers acts as a significant protective factor, reducing attitudes toward cyberbullying and promoting safe digital environments [12].

Educators and students should also know more about particular rules and regulations that regulate the usage of drones, such as the guidelines established by the Federal Aviation Authority (FAA). Beyond aviation rules, domestic drone usage raises profound Fourth Amendment privacy and surveillance concerns regarding data capture [62]. Therefore, establishing clear ethical protocols and securing informed consent as strongly recommended for drone-based environmental and health research operations are strictly essential steps for responsible K-12 classroom implementation [13].

4.5. From Theory to Practice: Implementation Considerations and Challenges

To introduce a drone soccer program into practice successfully, it is necessary to carefully plan it and take into account a variety of aspects, such as teacher training, curriculum integration, evaluation, and economic benefit. This section provides practical advice for educators and school administrators to institute a drone soccer program in a manner that is safe, effective, and sustainable.

4.5.1. Teacher Training and Professional Development

Professional development is identified as one of the most important aspects of the overall successful implementation of any new technology. Teachers must be familiar with the technology and confident in their proficiency to use it in the classroom. In the context of drone soccer, instructors should receive training in building, programming, and piloting drones, as well as the pedagogical strategies to teach the game. The TPACK framework is instrumental here, as it posits that successful technology integration requires an in-depth insight into the interactions between technology, pedagogy, and content [15], [63], [64]. This implies that educators must not only possess technical knowledge of drones but also understand how to apply this technology in a pedagogically sound manner to impart specific PE and STEM content effectively.

4.5.2. Curriculum Integration

Drone soccer can be integrated not only into the Physical Education (PE) curriculum but also across interdisciplinary subjects such as science, technology, engineering, and mathematics (STEM). The SAMR (Substitution, Augmentation, Modification, and Redefinition) model provides a useful theoretical framework for evaluating the depth of curriculum integration. At the substitution level, drone soccer functions as an alternative to conventional sports activities while maintaining similar learning objectives. At the augmentation level, drones can enhance the learning process by providing students with immediate and detailed feedback on their performance [19]. Moving to the modification stage, learning tasks are redesigned to incorporate specific technical skills and conceptual knowledge related to drone operation, strategy, and problem-solving [19]. Finally, at the redefinition level, drone soccer enables the creation of entirely new learning experiences that were previously difficult or impossible to achieve, such as developing students' understanding of three-dimensional spatial dynamics through first-person view (FPV) piloting and immersive technological interaction [19].

4.5.3. Assessment and Evaluation

Evaluation plays a crucial role in validating the effectiveness of a drone soccer program. Assessment in drone soccer should encompass a broad range of learning outcomes, including motor skills, game strategy, teamwork, and social-emotional development [54]. To achieve a comprehensive evaluation, several assessment methods can be employed. Performance-based tests can be used to evaluate students' ability to pilot drones, execute specific maneuvers, and collaborate effectively with team members during gameplay. Portfolios may encourage students to document evidence of their learning process, such as videos of drone flights, design journals, and reflective writings about their experiences and progress. In addition, self-assessment and peer assessment can foster critical reflection by allowing learners to evaluate their own performance and provide constructive feedback to their peers. These varied assessment approaches not only measure technical competence but also support the development of reflective, collaborative, and strategic learning skills.

4.5.4. Cost-benefit Analysis and Resources Needed

The introduction of a drone soccer program consumes a considerable amount of time and resources, including the cost of drones, the arena, software, and teacher training. A cost-benefit analysis should be conducted prior to implementation to ensure the educational benefits justify the investment. The Resource-Based Learning (RBL) model is a beneficial framework for supporting these requirements, focusing on the premise that students must have access to necessary resources to be successful [65]. In the case of drone soccer, these essential resources encompass the hardware (drones), the environment (arena), the curriculum, and adequate teacher support.

4.5.5. Barriers and Facilitators to Implementation

The implementation of drone soccer programs may be influenced by a range of barriers and facilitating factors at both the individual and institutional levels. The COM-B model (Capability, Opportunity, Motivation, and Behavior) offers a comprehensive theoretical framework for identifying and addressing these determinants of implementation success [59]. Within this framework, capability refers to teachers' possession of the necessary knowledge and technical competencies to effectively deliver drone soccer instruction. Opportunity encompasses the provision of adequate resources, infrastructure, scheduling flexibility, and organizational support to enable program integration within the school environment. Motivation reflects educators' attitudes, beliefs, and commitment toward the educational value of drone soccer as an innovative learning activity. Addressing these three interrelated domains is essential for fostering behavioral change among stakeholders and creating conditions that support the effective and sustainable implementation of drone soccer programs in educational settings.

Taken together, the synthesized findings not only highlight the implementation challenges of drone soccer in PE but also reveal its broader pedagogical and theoretical contributions. Furthermore, this review establishes a distinctive conceptual and pedagogical novelty by positioning drone soccer not merely as a supplementary educational technology, but as a transformative interdisciplinary platform that simultaneously integrates physical education, STEM learning, social-emotional development, and ethical digital citizenship. Unlike previous PE technology interventions that primarily focus on physical activity tracking, exergaming, or isolated robotics instruction, drone soccer uniquely combines embodied physical interaction, real-time cognitive decision-making, collaborative teamwork, and autonomous technology operation within a single learning ecosystem. The integration of the I-TPACK and SAMR frameworks further demonstrates that drone soccer operates beyond simple technological augmentation, reaching the "redefinition" level of pedagogy by creating learning experiences previously unattainable in conventional PE settings. This review therefore contributes a new evidence-based theoretical roadmap for future technology-enhanced PE curricula, particularly in preparing students for increasingly AI-driven and digitally mediated societies.

In the short term, the findings of this study provide practical implications for educators, curriculum designers, and school administrators seeking innovative approaches to modernize physical education through technology integration. The review offers an actionable framework for implementing drone soccer as a structured

pedagogical activity capable of improving student engagement, visual-motor coordination, collaborative learning, and interdisciplinary STEM participation. Furthermore, the proposed ethical awareness framework may assist schools in developing safer and more responsible guidelines for integrating autonomous technologies into educational environments. These findings may also support teacher professional development initiatives by emphasizing the importance of technological, pedagogical, and ethical competencies in future PE instruction.

In the long term, this study contributes to the broader transformation of physical education toward a digitally integrated and future-oriented learning ecosystem. As autonomous systems, artificial intelligence, and robotics become increasingly embedded in everyday life, drone soccer may serve as an early educational platform for preparing students with adaptive cognitive, technological, and social-emotional competencies required in Industry 5.0 societies. The integration of competitive robotics into PE also has the potential to reshape traditional perceptions of physical education from a solely activity-based subject into a multidisciplinary domain that bridges physical literacy, computational thinking, ethical awareness, and digital citizenship. Moreover, this study provides a foundational theoretical basis for future empirical investigations, policy development, and large-scale curriculum innovation related to emerging technologies in education.

Future research should focus on empirical validation within diverse educational settings, comparative studies with traditional team sports, and investigating the inclusivity of drone soccer for students with special educational needs. Furthermore, researchers must continue to address the ongoing infrastructural and pedagogical challenges teachers face when adopting technology in PE [66], explore the rapid evolution of digital technology in physical education teacher education (PETE) [67], and evaluate how structured dronagogy impacts specific cognitive and psychomotor outcomes in STEM curricula [68].

5. CONCLUSION

This scoping review establishes a novel evidence-based roadmap for integrating competitive robotics into physical education. A primary scientific contribution of this study is the empirical linkage between drone soccer and the dual-track development of students' psychomotor skills (such as visual-motor integration) and social-emotional competencies. Furthermore, by synthesizing current literature through the I-TPACK and SAMR frameworks, this research provides educators with a validated, actionable model for transitioning PE from traditional physical activities to interdisciplinary STEM learning. Finally, the proposed ethical awareness framework addresses a critical gap in the literature by outlining safety, privacy, and digital citizenship protocols necessary for the responsible deployment of autonomous systems in educational settings. Future research should focus on empirical validation within diverse educational settings, comparative studies with traditional team sports, and investigating the inclusivity of drone soccer for students with special educational needs.

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AUTHOR CONTRIBUTIONS

Conceptualization, W.W.; Methodology, F.W., Z.Q. and W.W.; Formal Analysis, F.W. and Z.Q.; Investigation, F.W. and Z.Q.; Resources, W.W.; Writing – Original Draft Preparation, F.W. and Z.Q.; Writing – Review & Editing, F.W., Z.Q. and W.W.; Supervision, W.W.; Project Administration, W.W.

INFORMED CONSENT STATEMENT

Not applicable. As this study is a scoping review based on previously published literature, it did not involve primary data collection from human or animal subjects; therefore, informed consent was not required.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

During the preparation of this manuscript, the author(s) utilized Gemini (Google AI) for linguistic refinement and structural optimization to enhance the overall readability and academic rigor of the text. Following this process, the author(s) reviewed and edited the content to ensure its accuracy and take full responsibility for the originality and scientific integrity of the work.

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