

Digitalisation in Physical Education: Addressing Challenges and Unlocking Educational Potential

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Abstract

Digital education emphasises the integration of technology to enhance and transform teaching, thereby fostering improved instructional models. It is set to become a significant driving force in promoting high-quality educational development. Despite advancements in digital physical education (PE), several practical challenges persist, including inadequate digital infrastructure, insufficient digital literacy among teachers and students, concerns regarding digital data security, difficulties in fostering students' independent learning, and an overreliance of PE teachers on digital technology. Addressing the challenges encountered when transitioning from traditional teaching methods to digital PE instruction, this study employs a literature review, logical reasoning, and hierarchical integration methods to examine the application of digital technology in PE teaching and its impact on instructional innovation. It explores core connotations, identifies key challenges, and proposes solutions to enhance the quality of digital PE. The findings reveal that diversified teaching methods, real-time resources, and precise instructional processes cultivate immersive, interactive, and personalised learning experiences, thereby enhancing student engagement, improving learning outcomes, and elevating overall education quality. By providing a robust theoretical foundation and practical insights, this study offers valuable guidance for educators and policymakers in advancing the digital transformation of PE.

Keywords: Digitalisation; Physical education teaching; Innovative; High-quality development

Abbreviations

PE Physical Education

VR Virtual Reality

AR Augmented Reality

BMI Body Mass Index



AHP Analytic Hierarchy Process
ICT Information and Communications Technology
RMSE Root Mean Square Error
DPE Dilemma Physical Education

Introduction

In the field of digital sports, developed countries have made remarkable progress, leading to the widespread application of digital technology in sports education. The combination of virtual reality (VR) and augmented reality (AR) technologies is widely used in PE teaching. These technologies allow students to safely experience various sports by simulating real-world scenarios, enhancing their interest, and improving learning outcomes. Penney et al. (2012) found that PE teachers regarded digital media as an effective method for assessing students' abilities, knowledge, and understanding [1]. Shewmake et al. (2015) found that students were significantly more interested in sports digitalisation [2]. Palao et al. (2015) used a mixed method design to compare teacher verbal feedback, video and teacher feedback, and video and student feedback. The results showed that the overall effect of video and teacher feedback was the most positive and significantly improved students' motor skills [3]. Thi et al. explored the application of the flipped classroom model in PE teaching [4]. The flipped classroom transforms traditional teacher-centered teaching into a student-centered collaborative learning environment. Chen et al. (2017) found a six-week digital game intervention in PE classes improved students' cardiopulmonary function while maintaining the enjoyment of physical education [5]. Gibbs et al. (2017) also found that the use of digital technology also saved more class time, allowing PE teachers to give students feedback [6]. Nation-Grainger (2017) conducted a 6-week intervention study in secondary schools and found that the use of heart rate monitors on the wrists of the test group and the resulting personal feedback showed that students burned more calories and ran longer distances [7]. Nowels and Hewit (2018) found that combining video and verbal feedback can effectively improve students' learning of sports skills [8]. Cao (2018) studied the role of multimedia digital platforms in university PE and found that it significantly enhanced students' participation and learning outcomes [9]. Ye et al. (2018) found that combining PE classes with digital games had a positive impact on students' body mass index (BMI) and physical fitness [10]. A comparative study by Cheng and Chen (2018) also showed that PE classes that used apps to record fitness data improved physical fitness values compared to traditional PE classes without apps [11]. In addition, Rekik et al. (2019) studied the effects of different teaching media,

including videos and images, in basketball. This suggests that video examples are more critical in acquiring sports-related knowledge than static images. Improve your basketball performance more effectively through dynamic video learning [12]. Digital empowerment of PE provides a diversified model, integrating electronic games into PE and stimulating students' interest. Andrade et al. (2019) found that using digital-physical games improved the classroom atmosphere [13].

The gamification approach stimulated enthusiasm, and the digital-physical games made motor learning more enjoyable. European countries are also exploring using big data to analyse students' sports performance and provide teachers with personalised teaching suggestions to further improve the quality of teaching. Sargenth and Casey (2019) found that from the perspective of PE teachers, digital media optimises teaching time and allows more activities to be implemented in the classroom [14]. The impact of digital technology in PE on students' physical Health is optimistic based on the results we have seen. Quintas-Hijós et al. (2020) found that digital, physical games are a good way to increase student motivation, as are direct digital feedback forms such as video recordings [15].

To sum up, the experience of developed countries in digital PE demonstrates that digital technology enhances teaching efficiency, increases student engagement, and supports personalised instruction. Integrating VR, AR, and data analysis technologies has enabled digital sports education to achieve significant potential and practical results. These experiences provide valuable references and inspiration for advancing digital sports education in my country.

The development of digital sports education in developing countries has increasingly been recognised as a crucial component in enhancing PE and promoting healthy lifestyles. Omondi (2020) points out that in Kenya, the introduction of digital tools like the "SportPesa" app has enabled students to participate in virtual coaching sessions and track their physical activities, thereby improving their overall fitness levels[16]. This shift towards digitalisation bridges the gap in resource availability and fosters a more inclusive and equitable educational environment. Sharma (2021) points out that the government of India, in partnership with NGOs, has launched the "Fit India" mobile app, which provides students with personalised fitness plans and exercise instructions to help them improve their physical fitness and motor skills[17]. The Vietnamese Ministry of Education and Training has officially approved several normative documents on digital teaching and, in collaboration with the Ministry of Information and Communications (MIC), has launched the "Internet Connection and Computers for Students' Programme". The initiative calls for donations of online

learning facilities for students from disadvantaged backgrounds. It aims to build innovative teaching in key areas across northern, southern, and central Vietnam, accelerating the digitalisation process of sports education in these regions [18] in China.

Regarding education for special children, Zhang (2020) proposed that cultivating their autonomous learning ability is key, which provides important insights for developing inclusive digital teaching strategies[19]. The Ministry of Science, Technology, and Innovation of Brazil introduced the "Brazilian Digital Transformation Strategy 2022-2026," proposing to achieve full internet coverage in all primary and secondary schools by 2024[20]. The Global System for Mobile Communications Association (GSMA) released the "Brazil Digital Roadmap 2023-2026," which again emphasised the importance of digital infrastructure in the sports education sector [21].

The "Outline for the Construction of a Powerful Sports Nation" (2019) points out that traditional PE concepts, content, and methods are insufficient and imbalanced in meeting the rapidly developing sports learning needs of students, thus urgently requiring the acceleration of the transformation, and upgrading of sports education[22]. Digitalisation in sports represents a significant breakthrough, creating new opportunities for sports development and establishing competitive advantages in the evolution of sports education. Digital teaching compensates for resource shortages and provides students with a more flexible and interactive learning experience while promoting the accessibility and equity of physical education. However, digital PE still faces several challenges, including inadequate infrastructure, low digital literacy among teachers and students, data ethics, security, and privacy protection concerns, students' autonomous learning habits, and the lack of standardised technology. From a digital perspective, this study leverages digital technology to address the current needs of sports development, explores the practical dilemmas and potential solutions for digital PE, and offers new insights for the high-quality advancement of sports education.

This study employs a literature review as its primary research method. A crucial aspect of PE teaching, learning, and assessment is using digital video. Various databases, including CNKI, WOS, and Google Scholar, were used to collect and organise research findings on education digitisation, PE teaching, and PE teachers' digital literacy. This review provides a wealth of supporting literature and a solid theoretical foundation for constructing digital-enabled PE.

Analysis of the connotation: PE teaching under the digital perspective

The digital empowerment of PE involves the comprehensive transformation of PE content, methods, and management through advanced digital technologies, including

artificial intelligence, 5G, big data, cloud computing, the Internet of Things, and blockchain. This process encompasses the digitalisation of PE content, the innovation and optimisation of instructional models, and the seamless integration of sports education with intelligent technology.

Diversification of teaching methods: digitalisation promotes the diversification and fairness of PE teaching

Digitalisation enhances the diversity of PE teaching methods. Integrating electronic game technology transforms PE content into a game-based learning format. A hybrid online and offline school model incorporates virtual role-playing to merge students' classroom performance with interactive games. This approach increases engagement, adds challenges to learning, promotes students' holistic development, and ensures equal educational opportunities for students from diverse backgrounds and abilities. Johnson et al. (2018) proposed that gamified teaching methods, including sports games and competitions, can enhance students' participation and interest in learning [23].

Teaching resources: innovation and practice of digital PE

Digital empowerment facilitates scenario-based PE in colleges and universities, offering learning opportunities beyond time and spatial constraints. Yuan (2023) proposed that digital technology overcomes these limitations by providing diverse teaching resources, including videos, audio, and images, making PE more engaging and practical [24]. Overcoming regional restrictions through live video and remote interaction allows students to arrange their study time more flexibly, enhancing the convenience and autonomy of learning.

This approach to teaching design and delivery stimulates students' interest, improves engagement, and enhances their comprehension and retention of knowledge. The National Smart Education Platform 2.0 version (2022) highlights that over 100 high-quality sports practice courses are available online through such platforms as AiKeCheng, YuKeTang, ZhiHuiShu, and the Ministry of Education's Smart Education Platform. These resources adapt to new teaching formats, contribute to forming a comprehensive sports course resource group, and drive innovation in teaching content [25].

Teaching process: digital technology helps PE teaching effect evaluation and accurate feedback

Through digital technology, the effectiveness of students' sports skill learning can be accurately assessed, and timely, precise feedback on teaching outcomes can be provided

to enhance instructional effectiveness. Jiang (2023) pointed out that digital tools and technologies can track students' performance, learning progress, and participation in the teaching process, support independent learning, and facilitate access to essential information [26]. This precise monitoring and feedback of participation helps teachers adjust teaching strategies promptly, thereby achieving better teaching results. Zheng (2023) studied the application of digital proofreading technology in digital publishing, proving that it can accurately detect and correct errors. This technology can also be applied to the precise recording and analysis of jump rope training data to improve the accuracy of training effect evaluation [27].

Chen Junfei (2022) proposed integrating intelligent sensor technology to enhance the teaching accuracy of digital sports education through research [28]. Ma's (2021) research explores how to use big data information fusion and data mining technology to build a new University PE evaluation system to make up for the shortcomings of traditional methods in student learning processes and feedback[29]. Guo (2023) proposed a PE effectiveness evaluation model based on the analytic hierarchy process (AHP) algorithm, which significantly improved the accuracy of evaluation, with its root mean square error (RMSE) being only 1.923[30]. Akbar's (2016) research indicates that educators must evaluate and adopt new technologies to enhance teaching effectiveness in higher education [31]. This viewpoint also applies to the field of PE, where the introduction of advanced digital technology can effectively improve teaching quality and the learning experience of students. See Figure 1

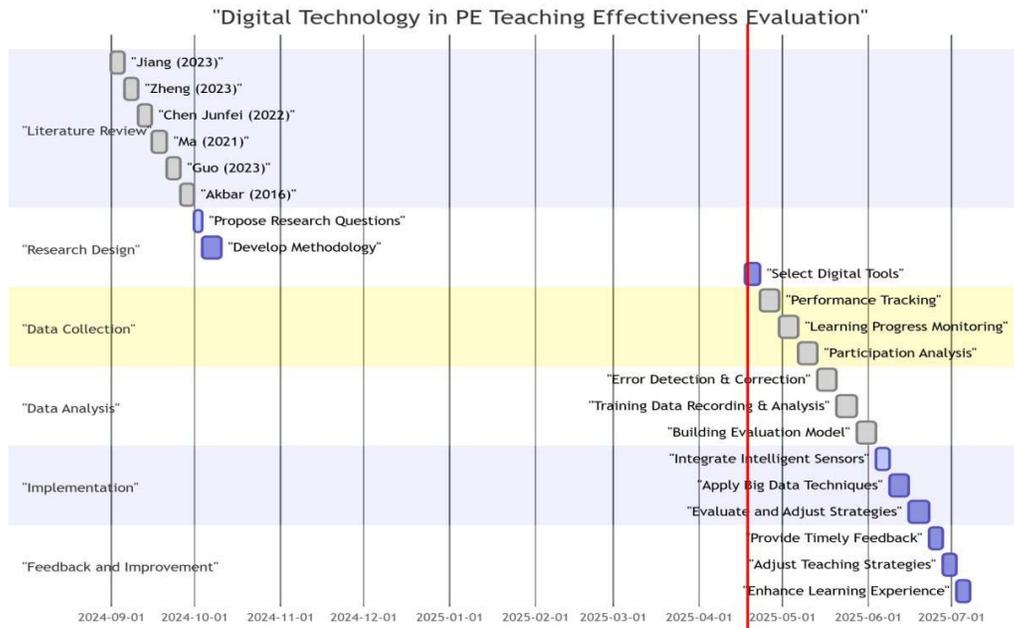


Fig. 1 Analysis of the connotation: PE under the digital perspective
 Sources : Gao et al., (2015)[32]

Dilemma: PE teaching under the perspective of digitalization

Resource dilemma: lack of digital infrastructure

The 4G network coverage rate in African countries remains low, and network services are inadequate and unevenly distributed, leading to significant regional disparities in school education and further exacerbating the digital divide. With only 6.4% of the population covered by 5G networks, schools face a severe digital equipment and resources shortage. According to the 2022 National Education Development Statistical Bulletin, China has 15,000 general high schools with varying levels of compliance in meeting facility and equipment standards.

A 2020 survey on students experiencing online learning difficulties revealed that two-thirds of respondents attributed their challenges to a lack of appropriate equipment for attending online classes [33]. The lack of essential infrastructure, such as network coverage, data centres, and cloud services in remote areas, has resulted in unstable network connections in schools, making it challenging to effectively monitor online and offline teaching and ensure a seamless instructional process. For example, in a smart sports bracelet experiment conducted at a middle school, the data upload and

analysis functions were severely restricted due to an unstable network connection, ultimately impacting the project's effectiveness. The lag in technical infrastructure can lead to slow data transmission, system crashes, or security vulnerabilities, further complicating monitoring efforts.

Additionally, inadequate technical facilities may prevent the timely retrieval of critical data feedback, making it challenging to track learning progress and ensure effective instructional control - specific dilemma. Goodyear (2015) explored the challenge of teachers' inability to integrate digital technology into physical education, emphasising the disconnect between technological training and teaching practice. Legrain (2015) empirically examined the dilemma of excessive reliance on digital tools, which may weaken students' intrinsic motivation for physical activity. Similarly, Thomas (2006) highlighted practical challenges such as the low utilisation rates of technological devices and inadequate technological adaptability among teachers and students.

Casey (2017) pointed out that digital tools might reduce face-to-face collaboration and emotional connections in physical education classrooms, further complicating the teaching process. Williamson (2015) also discussed ethical concerns regarding data collection from wearable devices, emphasising the risks of student privacy infringement. These studies illustrate the multifaceted challenges of integrating digital technology into physical education, encompassing technological, pedagogical, motivational, and ethical dimensions.

Dilemma literacy: teacher and student

Li (2023) mentioned that information and communications technology (ICT) professionals account for less than 1% of the employed population in Uzbekistan. Many lack basic Internet skills in nine countries and regions along the Belt and Road, including Iraq, Pakistan, and the Philippines. The proportion of individuals who can find, download, and install software and applications is less than 10%, highlighting the urgent need to continue promoting "digital literacy." [34]. In rural schools in India, PE teachers have not received training in digital teaching, resulting in the PE monitoring equipment being provided becoming "idle assets" and unused. This further emphasises that digital teaching capacity training for teachers is a common and urgent problem that needs to be addressed globally.

Teachers have not formed the value of using digital technology to improve teaching effectiveness. PE teachers have limited application in digital teaching, lack awareness of digital PE, lack the efficacy and role of new technologies in PE, and cannot master

digital technology. First, as a new technology, digital teaching presents specific operational difficulties and skill requirements, necessitating proficiency to utilise its advantages entirely in PE instruction.

Second, many PE teachers, particularly those accustomed to traditional teaching methods, lack awareness of digital technology. Psychological barriers exist in adapting to new pedagogical models, with some teachers resisting change. Third, disseminating effective teaching strategies and methodologies remains challenging, especially for older educators who may struggle to adopt digital tools and technologies. A survey on the age structure of teachers found that while young and middle-aged teachers constitute the majority, the proportion of teachers over 46 years old in towns and rural areas is slightly higher than in other regions, at approximately 15.2% (715,000). This figure accounts for 7.4% (266,000) and 10.5% (200,000) of teachers in county towns and cities, respectively, making the widespread promotion of digitalisation in PE more difficult [35].

Schools also lack digital development initiatives, including comprehensive, systematic, and targeted efforts to enhance students' digital capabilities and awareness. Rahman (2023) pointed out that while 40% of university-level students in Bangladesh participate in online teaching, most students remain sceptical about various aspects, including adapting to online learning, network issues, and a lack of digital knowledge [36].

Security dilemma: digital data security issues

If data privacy in the digital empowerment of PE is not adequately protected, it can lead to serious consequences and legal issues. Regarding system construction, unclear responsibilities between departments and information barriers make it challenging to define data security responsibilities, causing traditional management processes to struggle with new data processing challenges. From a technical perspective, outdated storage devices and weak network infrastructure pose security risks. Compatibility issues and leakage risks hinder data interaction due to differences in formats and interfaces while integrating security protection for heterogeneous systems presents technical bottlenecks.

Additionally, significant individual differences in data security awareness among teachers and students make awareness cultivation particularly challenging. Some teachers and students do not prioritise data security, exhibit a weak sense of proactive protection, and struggle to translate knowledge into practical operational capabilities. In permission management, various teaching data users have different access needs,

which complicates establishing an accurate and efficient permission management mechanism. Improper allocation of permissions can easily compromise both security and operational efficiency.

Habits dilemma: students' independent learning

While the PE teaching model under the digital perspective enhances teaching development, it also challenges students' cultivation of independent learning habits. First, the vast amount of fragmented information in the digital environment may lead to distractions, making it difficult for students to focus. Additionally, students may develop negative emotions during the learning process, struggling to concentrate on systematic sports knowledge and skill acquisition, ultimately resulting in confusion and disengagement. The disparity between digital learning scenarios and actual sports practice makes it challenging for students to translate their acquired knowledge into practical sports skills, impacting their enthusiasm and self-confidence in independent learning.

Additionally, students may struggle to effectively filter and select learning content that best suits their needs, which can negatively affect their learning outcomes. Furthermore, excessive reliance on digital devices and tools can reduce students' intrinsic motivation to learn and hinder their ability to engage in deep problem-solving when these technological aids are unavailable. This dependency weakens their willingness to engage in self-training and improve their skills in real sports situations.

Technology dependence: PE teachers are overly dependent on digital technology

The development of technology in digital PE teaching still faces significant challenges and uncertainties. First, while teachers and students can utilise technical tools to conduct or participate in teaching, they often lack an understanding of these technologies' underlying operational mechanisms and logic. This limitation reinforces habitual dependence on technology, making it challenging to reduce reliance. As dependence increases and users have limited control over the tools, technology may gradually erode the teacher's dominant role in instruction.

Second, some digital PE tools rely on algorithms for teaching evaluation and lesson planning. The algorithm may generate biased evaluation results if the teaching data contains an imbalanced proportion of samples from specific genders or physical fitness levels. This can disadvantage certain student groups regarding teaching resource allocation and personalised guidance, ultimately impacting their enthusiasm for PE and limiting their development opportunities. Details refer to Figure 2.

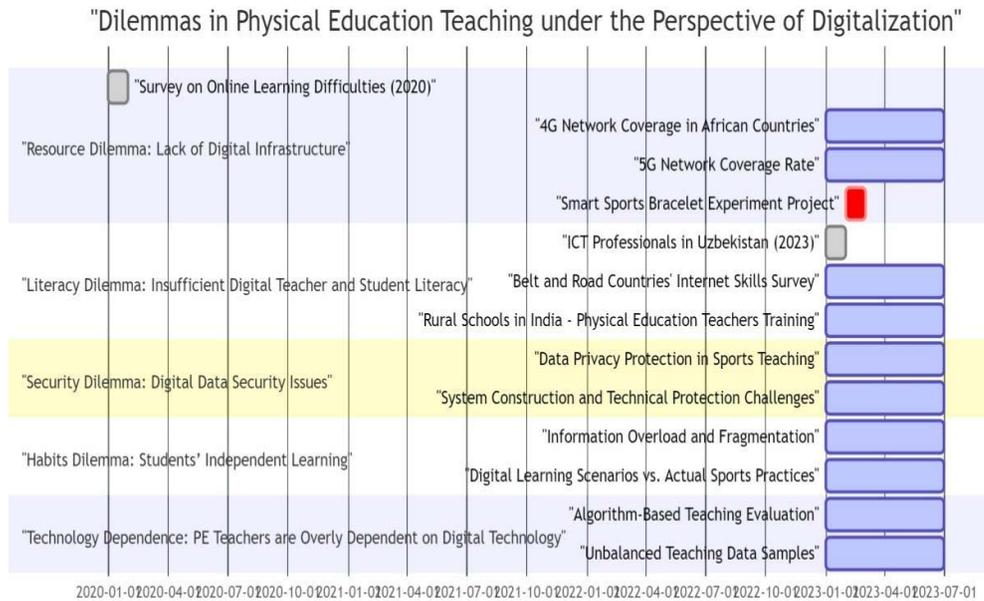


Fig. 2 Practical dilemma: PE teaching from the digital perspective

Solution: DPE

Strengthening the foundation: government, enterprises, and schools

First, the government should provide support through policy formulation and financial investment. For example, the Guiding Opinions on Promoting the Construction of New Education Infrastructure and Building a High-Quality Education Support System, issued by the Ministry of Education and six other departments in 2021, emphasised that by 2025, a dedicated education network and an "Internet + Education" platform will be established to serve as a digital foundation for the high-quality development of education [37].

In its Digital Education Action Plan, the European Union highlights the importance of digital technology in education. It encourages member states to integrate digital tools into PE to enhance student engagement and learning. Additionally, the plan emphasises increasing financial investment to address regional disparities in educational resources. Efforts focus on improving network coverage, expanding data centres, and strengthening cloud service infrastructure, particularly in remote areas. These measures aim to ensure that schools have stable network connections, access to digital teaching

equipment, and can effectively monitor online and offline teaching, thereby supporting comprehensive and high-quality PE instruction.

Secondly, as the main battlefield of education, schools should actively respond to the government's call and make every effort to promote digital teaching reforms. Qi (2023) pointed out that schools should increase investment in campus network infrastructure, enhance campus network bandwidth and coverage, and support digital PE teaching. Data transmission ensures the smooth operation of video playback and online communication during teaching [38].

Update existing sports facilities and equipment and introduce advanced digital teaching management software, equipment, or platforms. Finally, it will introduce technological advantages to provide technical support for digitalising PE teaching. Companies like iFlytek, AI, DeepGlint, and Megvii Technology have entered the bright PE scene on campus, providing schools with advanced digital teaching platforms with personalised, situational, and intelligent new applications to create a more attractive learning experience. Enterprises and schools jointly develop suitable digital course resources to help improve the school's digital teaching level. The government, schools, and enterprises work together, clarify responsibilities, and form a powerful synergy to promote the digitalisation of PE, the development of school PE, and the development of digital PE teaching models.

Capacity improvement: strengthen digital technology education and improve the digital literacy of multiple subjects

Teachers' improvement. In February 2023, China's Ministry of Education issued the Teacher Digital Literacy industry standard, which defines teachers' digital literacy requirements and mandates continuous improvement. First, regular training sessions are provided, balancing theoretical and practical aspects. Personalised learning paths are designed based on teachers' diverse backgrounds and needs, with customised content and plans to enhance engagement. Learning interest is further stimulated through case analysis and experience sharing. Additionally, a feedback mechanism is established to address teachers' learning difficulties through online Q&A support. Claude Miller (2016) proposed that the e-reflection tool at the University of Zurich helps new teachers enhance their digital skills, demonstrating the effectiveness of structured digital literacy development programs [39].

Secondly, to cultivate teachers' innovative consciousness, teachers should understand the importance of innovation and inspire their thinking by combining cases.

A reward mechanism for innovative teaching achievements should be established to encourage teachers to participate in creative activities. Build a platform for teachers to communicate and cooperate, such as online forums, blogs, and workshops, to promote communication and interaction among teachers. Despina Kaitani (2017) enriched the teaching content and promoted students' comprehensive understanding of multiple fields [40].

Students Improvement. Schools should develop a comprehensive and systematic digitalisation plan for students and incorporate digital capabilities and digital awareness into the school's overall education system. They should also establish special digital education courses that cover the basics of digital technology, information literacy, and digital learning methods. Through a combination of theoretical teaching, case analysis, and practical operations, students' understanding application of digital technology is improved, and their awareness of actively using digital technology to solve learning problems is stimulated.

Parents improvement. The school has established a collaborative digital sports education mechanism to enhance communication and cooperation between home and school. Through digital platforms, parents can stay informed about their children's progress in sports learning. Additionally, the school regularly releases digital PE resources and updates, enabling parents to track their children's learning activities and engagement in physical education.

Security guarantee: regulating data security mechanisms to facilitate the digitalisation of PE

Strengthening data protection awareness and enhancing data risk prevention and control capabilities are essential. Wang (2022) emphasised the need to strictly adhere to the data risk control regulations outlined in the Data Security Law of the People's Republic of China. This includes mastering risk assessment, detection, and supervision processes and implementing effective risk identification and prevention strategies. A comprehensive approach to data privacy protection should be adopted to ensure security and compliance [41]. In digital PE teaching, collecting, and uploading relevant student data for analysis to obtain behavioural feedback is necessary. With the widespread application of digital technology, the amount of data involved continues to increase. Therefore, adequate measures must be taken to protect data privacy. Schools should establish a sound data management system, clarify the departments and management processes responsible for data security, and ensure the orderly implementation of data

security work. At the same time, schools must enhance the security of teaching data storage and transmission. It is essential to strengthen data security awareness among teachers and students, increase their attention to data protection, and guide them in adequately using data.

Additionally, schools should establish a strict data access rights management mechanism to ensure that only authorised individuals can access and utilise teaching data. For example, students can view their personal sports training and equipment usage data with proper authorisation. At the same time, teachers can access sports data related to course assessments and the evaluation of all students in their class.

Teaching application: cultivating students' independent learning habits and abilities

Digital education is centred on student learning, where students take the lead in their educational journey, learning independently based on their interests, needs, and pace. Teachers support students' learning process as guides, facilitators, and resource providers. The abundance of resources, personalised learning paths, and the convenience of digital PE teaching have significantly enhanced students' learning experiences, fostering independent learning habits and improving their abilities. Specifically, this includes:

Schools can offer digital courses to help students develop information searching, screening, and evaluation skills, enhancing their ability to acquire and process information effectively. Teachers play a crucial role in cultivating students' ability to search for PE-related information by guiding them in utilising digital libraries, online databases, and other educational resources. Additionally, teachers can support students in mastering effective exercise methods and techniques through video explanations and sports competitions, providing targeted demonstrations and guidance tailored to students' characteristics and needs.

Students should also be able to independently create lesson plans, select learning resources, and manage their class time effectively. Digital teaching tools can further stimulate students' initiative and enthusiasm for learning. For example, companies like iFlytek, AI, DeepGlint, and Megvii Technology have introduced advanced digital PE applications into school campuses, integrating personalised, gamified, situational, and intelligent features to create a more engaging and dynamic learning experience.

Ethical correction: resolving digital ethical security and cultivating the ethical literacy of teachers and students

Luo (2024) pointed out that by improving laws and regulations and strengthening technical support, the generation, accumulation, and diffusion of ethical risks in digital PE can be avoided to the greatest extent possible [42]. Build an ethical safety protection system to ensure digital PE and sustainable development, realise the integration of technology and sports education, and provide students with a safe, educational environment. First, the digital ethical risk literacy of teaching subjects should be improved. Wu et al. (2023) pointed out that teachers and students should enhance their awareness of ethical risk prevention and control in the digital transformation of teaching and improve their ability to identify and deal with ethical risks through digital risk education and learning [43].

Secondly, teachers should abide by the ethical standards for applying digital technology, assume the responsibility of risk screening and assessment of digital teaching materials and digital educational products, and avoid technical security risks caused by defects in innovative educational products or technological deficiencies. Finally, data privacy protection and digital ethics education should be carried out for students to enhance their self-protection awareness and discernment. Let students understand their rights and obligations in digital PE, learn to use digital tools correctly, and avoid damage to their rights and interests due to improper operation. At the same time, establish a channel for students to appeal for their rights and interests. When students find that their rights and interests are infringed, they can give feedback quickly and get proper treatment. Please refer to Figure 3.

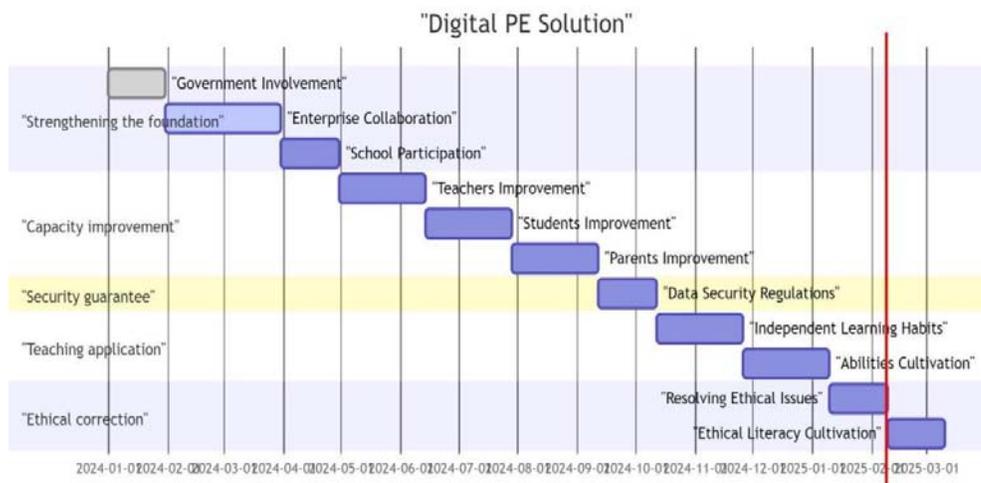


Fig. 3 PE teaching relief path under digital view

Discussion

Based on the impact of digitalisation on the transformation of physical education, this study discusses the significant challenges currently faced in digital physical education. It also proposes solutions to implement digital teaching effectively in physical education. Various scholars have further explored aspects of this topic. Wu et al. (2014) pointed out that a study found that the three-dimensional motion capture system uniquely enhances the effectiveness of physical education and improves sports skills.

Additionally, it can provide scientific and practical sports data to support PE instruction [44]. Mei and her team (2021) mentioned the possibility and potential advantages of hybrid education (i.e., combining MOOCs with traditional PE) [45]. Tony Weir (2009) proposed that the application of digitalisation in physical education teaching has been extensively studied, with results indicating that digitalisation has a profound and innovative impact on PE instruction [46]. Junfei et al. (2022) proposed that it is deeply recognised that digital teaching has emerged with the development of digitalisation and even has the tendency to replace traditional offline teaching in some fields [47]. However, while the virtual PE environment created by digital technology can provide an immersive experience, prolonged exposure may cause physical discomfort, such as dizziness and visual fatigue.

Han (2020) noted that digital technology inevitably fragments learning into smaller tasks, leading to distractions and reducing students' ability to maintain focus [48]. At the same time, competitive pressure in the virtual environment and the improper guidance of virtual characters may negatively impact students' psychological well-being, leading to anxiety, feelings of inferiority, and other emotional distress. Additionally, these factors may even hinder the development of students' correct values and sportsmanship [49]. Junfei (2022) studied the application of digitalisation in physical education using intelligent sensor technology, leveraging its high precision and ability to recognise movements. The research focused on students' performance in table tennis, gymnastics, martial arts, soccer, and the 100-meter sprint test. The results indicated that digital teaching significantly improved student performance. Similarly, Junfei (2022) noted that digitalisation led to superior results in various tests compared to the control group when applied to the experimental group.

Discussion: Dilemma physical education (DPE) theoretical framework. The Constructivism perspective systematically deconstructs the practical framework of digital-physical education, revealing multiple dialectical relationships in technological empowerment. The findings indicate that the blended teaching model, supported by technologies such as 3D virtual simulations, successfully achieves the theoretical

integration of embodied cognition (Piaget, 1963) and social constructivism (Vygotsky, 1978). This is reflected in two key aspects: (1) Digital twin technology creates a dual experience space of "embodied-virtual" interaction; (2) Intelligent collaboration platforms reconstruct the relational network between teachers and students. However, it is essential to note that the technological intervention in PE teaching has led to a threefold paradox of alienation when the data granularity of wearable devices surpasses a critical threshold, quantitative tracking may deconstruct the embodied narrative inherent in physical education (Sweller, 1988), creating a tension with the core principles of embodied cognition theory.

Further analysis reveals that the capability gap in digital transformation exhibits a significant "Matthew Effect." Teacher training programs designed under the TPACK framework (Mishra & Koehler, 2006) enhance digital scaffolding in well-resourced schools but face dual constraints of hardware deficiencies and cognitive overload in underprivileged schools. This polarisation effect suggests introducing technology may exacerbate educational inequality, which conflicts with the activity theory principle of tool adaptability (Engeström, 1987). To address ethical dilemmas, this study proposes a dynamic governance framework highlighting two innovative dimensions: (1) The implementation of a digital badge system visualizes metacognitive capabilities, enhancing the operationalization of self-determination theory (Deci & Ryan, 1985); (2) The introduction of an algorithm audit mechanism delineates ethical boundaries for the application of learning analytics. However, the framework still faces limitations in cultural adaptability, particularly in collectivist cultural contexts, where the compatibility between personalised recommendation systems and group learning dynamics requires further exploration. See Table 1.

Table 1 DPE theoretical framework

This Research	Key Concepts & Issues	Theory Integration and References
Analysis of the Connotation: DPE	DPE: student-centered and shifts the role of teachers to multi-dimensional facilitation	Piaget et al. (1963) stated that constructivism promotes experiential learning through digital platforms, virtual simulations, and gamification
Dilemma: DPE	Various challenges hinder the integration of digital technology into PE teaching	Siemens (2005) stated that constructivist learning requires a supportive environment, but the dilemmas create barriers to effective learning and engagement
Resource Dilemma: Lack of Digital Infrastructure	Inadequate network coverage, data centers, and cloud services in some regions limit the implementation of DPE	Kolb (1984) stated that without technological resources, scaffolding and experiential learning opportunities through digital tools are restricted
Literacy Dilemma: Teacher and Student	Insufficient digital literacy among teachers and students hinders the effective application of digital PE tools	Mishra and Koehler (2006) stated that constructivist learning depends on competent facilitators and learners who can navigate digital environments
Security Dilemma: Digital Data Security Issues	Privacy concerns arise from wearable devices, data tracking, and digital monitoring	Sweller (1988) stated that constructivism emphasizes ethical collaboration, requiring trust and security in digital learning spaces
Habits Dilemma: Students' Independent Learning	Students struggle with self-regulation and engagement in digital PE environments	Deci and Ryan (1985) stated that constructivist theory supports autonomy through self-directed learning and scaffolding to aid student progress

Technology Dependence: Overly Dependent on Digital Technology	Excessive reliance on digital tools may diminish face-to-face collaboration and teacher autonomy	Bandura (1977) stated that constructivist learning encourages a balance between digital support and human interaction
Solution: DPE	Strategies to overcome digitalization challenges in PE	Engeström (1987) stated that constructivism informs best practices in digital learning by ensuring interactive, student-centered, and ethical digital PE implementation
Strengthening the foundation: Government, enterprises, and schools	the development of school PE, and the development of DPE teaching models	Qi (2023) stated that increasing investment in campus network infrastructure, enhancing campus network bandwidth and coverage, and supporting digital PE teaching
Capacity Improvement: Digital Technology, Digital Literacy	Training programs enhance digital skills among teachers and students	Puentedura (2010) stated that scaffolding is supported by equipping learners and educators with the necessary digital competencies
Security Guarantee: Regulating Data Security	Implementing strict digital security measures to protect student and teacher data.	Williamson (2015) stated that ensuring a safe constructivist learning environment requires prioritising ethical considerations
Teaching Application: Students' Independent Learning Abilities	Digital PE should focus on fostering student autonomy and engagement	Csikszentmihalyi (1990) stated that constructivism aligns with experiential and self-directed learning
Ethical Correction: Digital Ethical Security, Ethical Literacy	Establishing digital ethics training programs to address security and ethical concerns in digital PE.	Thomas (2006) stated that ensuring digital interactions follow constructivist principles requires fostering collaborative and responsible learning

Conclusion

The study systematically examines the fundamental connotation of high-quality development in digital PE teaching, addressing real-world challenges and proposing solutions. It explains the underlying logic of the high-quality development of digital PE and explores how digital technology transforms PE teaching models. The conclusion states that the transformation of Digital Physical Education (DPE) faces numerous challenges and opportunities in today's society. Based on the analysis of the connotation of digital PE teaching, five significant practical difficulties are summarised:

The key challenges identified include insufficient digital infrastructure, a lack of digital literacy among teachers and students, inadequate data security and privacy protection, poor independent learning habits, and excessive reliance on technology. To address these dilemmas, specific solutions were proposed, including strengthening infrastructure construction, enhancing the digital capacity of teachers and students, improving data security management mechanisms, fostering students' independent learning abilities, and standardising ethical guidelines for technology implementation.

At the same time, in response to the challenges posed by the five significant dilemmas, it is essential to uphold a people-oriented ethical foundation, enhance ethical standards and legal regulations, and comprehensively regulate and oversee the entire design, development, and application process of digital teaching products. Emphasising the core of digital teaching with teachers and students as the central focus, fully leveraging the educational value of digital technology, and advancing the enhancement of education quality in the digital era.

Limitations and future study

The limitations of this study include several key aspects. (i) Regional and geographical constraints: The study focused exclusively on documents in Chinese and English, excluding significant sources in other languages such as German, French, and Russian, which may have limited the comprehensiveness of the analysis. (ii) Limited field observation: The researchers could not conduct in-depth field observations in representative schools or teaching institutions, restricting their ability to fully understand digital transformation's specific status and practical challenges in PE teaching. As a result, issues such as algorithm bias and privacy leakage were not

discussed in detail, nor was an operational, ethical review framework proposed, highlighting the need for a broader scope and deeper exploration in future studies. (iii) Technological limitations: While the study is reality-oriented and provides practical guidance, it did not incorporate big data, artificial intelligence, or other data mining and analysis technologies due to time and technical constraints, thereby limiting the analytical depth.

Future research will aim to overcome these challenges by exploring the application and effectiveness of digital PE, addressing five significant difficulties to advance the field further. DPE emphasises the integration of technology and education, adopting a hybrid online and offline learning model that is student-centred and transforms the role of teachers from a traditional approach to a multi-dimensional teaching model. This paradigm enables students to use virtual reality technology to acquire theoretical knowledge and online technical demonstrations. Building on this foundation, digital PE is expected to transition from traditional to intelligent teaching models. Furthermore, with continuous technological advancements and evolving societal needs, a key challenge remains fully leveraging digital tools to enhance teaching effectiveness while preserving the fundamental essence of education.

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Data availability

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

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Ethics approval and consent to participate

It is not applicable. This study does not involve human subjects, animals, or sensitive personal data, so it does not require approval from an ethics committee or institutional review board.

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Competing interests

The authors declare that the study was conducted without commercial or financial relationships that could create a conflict of interest.

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