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Research Hotspots and Trend Analysis of Digitalization in Physical Education

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Abstract

Purpose – This paper will systematically review the research landscape, hotspots and evolutionary trends of digitalisation in physical education (PE) to meet the growing demand for evidence-based knowledge on how digital technologies are changing PE at the university level.

Design/Methodology/Approach – This study retrieves 480 English papers (2010–2025) from Web of Science Core Collection and Scopus via bibliometrics. Visual analyses including publication trends, international-institutional partnerships, author networks, keyword clusters and burst words are performed with CiteSpace 6.2.R4.

Findings – Main findings: (1) PE digitalisation research has expanded rapidly since 2020; (2) Global research cooperation is scattered without a stable core team; (3) Digital technology integration must centre on pedagogy; (4) Hot topics cover technical application, teaching practice, teacher training and comprehensive learning effects; (5) Research has shifted from basic ICT to AI-enabled precise teaching, focusing presently on teachers' digital literacy, student engagement and ethical risks.

Research Implications – This bibliometric study has constructed the knowledge system of PE digitalisation and offered theoretical and practical references for scholars, educators and policymakers interested in promoting digital innovation in physical education.

Keywords: Physical Education; Digitalization; Knowledge Mapping; CiteSpace; Research Trends
JEL Classifications: I20,O33,Z20

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I. Data Sources and Research Methods

1. Data Sources

To address both the impact of sample bias and comparability issues with foreign studies, this paper uses the Web of Science (WoS) Core Collection and Scopus as data sources and selects a time range of 2010-2025. Given the research topic "Application of Digital Technology in Physical Education in Higher Education", a preliminary literature review was carried out to identify common terminology and ensure both precision and completeness. "PE" and related terms were selected as the main search keywords, combined with "digital*" and its synonyms, and limited by terms such as "colleges" and "students". At the same time, to reduce the interference of a large number of unrelated medical papers, terms such as "patient*", "clinical", and "injury*" were excluded. The last search query is as follows:

TI=("physical education" OR "PE" OR "physical training" OR "sport education" OR "sport*" OR "movement skill*" OR "sport* skill*" OR "motor performance" OR "motor learning" OR "skill learning" OR "skill acquisition") AND TS=("college" OR "university" OR "higher education" OR "student*" OR "teacher*") AND TS=("digital*" OR "artificial intelligence" OR "AI" OR "technolog*" OR "media" OR "web-based" OR "online learning" OR "virtual reality" OR "augmented reality" OR "data-driven") NOT TS=("patient*" OR "clinical" OR "rehabilitation" OR "therapy" OR "disorder*" OR "disease*" OR "injur*" OR "hospital")

The first search found 1,582 papers in all the databases. Only the original Articles and Review papers were kept, excluding peripheral disciplines and non-English publications; thus, 932 relevant records remained. According to the PRISMA flow diagram for further de-duplication and screening, a final high-quality dataset of 480 publications suitable for CiteSpace analysis was obtained.

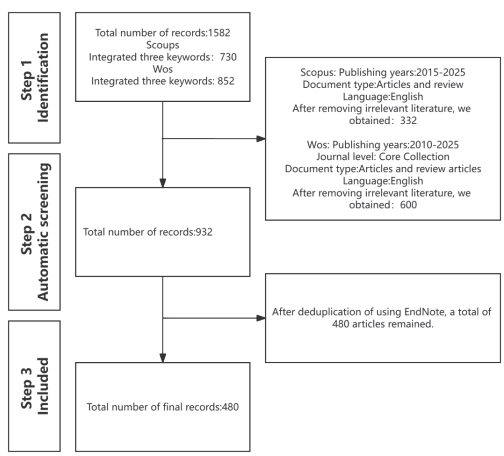

Figure 1. Flowchart of literature screening

Source: Compiled by the author

2. Research Methods

CiteSpace 6.2.R4 software is employed in this study to create knowledge maps and present the structure of knowledge and its development path in the field, thus addressing the shortcomings of "subjective induction" (Chen, C., 2017) of traditional reviews. The intellectual system, research hotspots and evolutionary trends of this field are shown systematically in dimensions such as the number of annual publications, co-citation networks, country-institution-author cooperation networks, keyword co-occurrence with LLR clustering, burst terms and time-zone views. Standardise the parameter settings to a time slice of 1 year and a g-index (k=25) threshold. LLR clustering algorithm was used, and a Modularity (Q) > 0.3 and Weighted Mean Silhouette (S) > 0.5 were considered to indicate a valid structure. This way can show the whole situation and future directions of research in "digitalisation" and "physical education".

II. Analysis of Current Research Status

To find out how far a field has progressed over time and where it is deficient, one can start a new study (Webster & Watson, 2002). Four attributes of the present digital applications in PE are presented here: publication trends, country and institutional networks, author collaboration, and the body of highly cited works that form the knowledge system of the field.

1. Trends in Annual Publication Volume

The number of publications each year can show whether a field has grown due to new technology or changes in society. Research on digital applications in Physical Education has passed through three recognizable stages (see Figure 2).

2010-2015 (Initial Exploration Period): Only 27 papers were published in this time, and the field was relatively new. Mobile Internet, smart terminals and 4G networks have created the technical conditions for digital teaching, but in practice, it has not been widely implemented. Most of the previous studies have only covered the theory and small-scale application tests; no systematic practical research has been carried out.

2016–2019 (Stable Growth Period): With the wider availability of digital tools, the number of publications reached 67. Smart wearables, high-performance mobile devices and cloud platforms have provided researchers with a more stable foundation for studying technology-PE integration. Instead of asking whether digital tools could be used in physical education classes, scholars began to explore how to apply video-based feedback, motion-sensor performance observation and app-assisted independent practice. Thus, the scale of production gradually increased.

2020-Present (Rapid Expansion Period): A total of 386 papers were published in this time, and the latter part was accelerated by the COVID-19 pandemic. School closures and social distancing requirements have led

many education systems around the world to switch to online and blended learning rapidly; this has created an urgent demand and new practical scenarios for digital PE (Wollscheid et al., 2023). At the same time, Artificial Intelligence (AI), Computer Vision and Virtual Reality (VR) have also shown some new research paths. The result was not only an increase in the number of publications but also a significant rise in citations; thus, PE digitalisation had become a serious problem for education and technology.

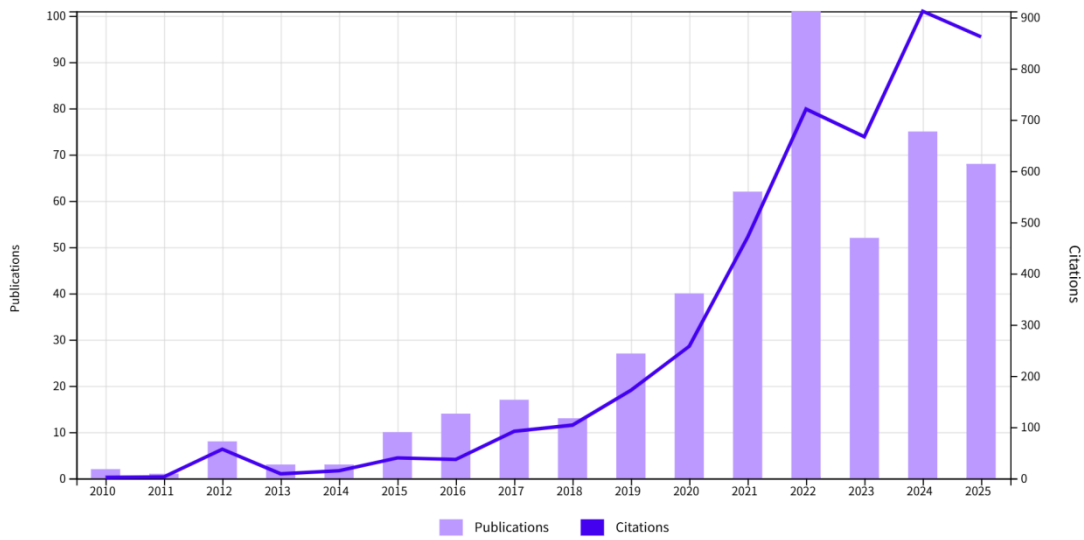

Figure 2. Annual Publications and Citation Rates in the Field (2010–2025)

Source: Authors' own visualization generated using CiteSpace (Version 6.2.R4) based on bibliographic data retrieved from the Web of Science Core Collection.

2. Analysis of Country Cooperation Networks

There are 88 countries (nodes) in the country co-occurrence map and 110 links connecting them; the network density is 0.0287. It can be seen that, although some foundations for cooperation among these countries have been laid in this field, the actual cooperation is not close. As shown in the table, there are 16 countries with more than 10 published papers. China is in the lead with 164 publications, followed by the USA (82), Spain (33), the UK (21) and South Korea (21), showing that these countries have been paying attention to the problem for some time.

Table 1. Publication Status of Major Countries in This Research Field from 2010-2025

Count	Centrality	Year	Countries
164	0.12	2012	PEOPLES R CHINA
82	0.13	2012	USA
33	0.27	2015	SPAIN
21	0.1	2016	ENGLAND
21	0.03	2016	SOUTH KOREA
20	0	2011	TURKEY
19	0.09	2012	AUSTRALIA
16	0.14	2020	INDONESIA
14	0	2015	GERMANY
14	0	2015	UKRAINE
14	0	2016	RUSSIA
11	0.2	2012	IRELAND
11	0.05	2022	MALAYSIA
11	0	2019	BRAZIL
9	0.04	2022	PHILIPPINES
9	0	2021	KAZAKHSTAN
8	0.01	2016	IRAN
8	0.06	2010	CANADA
6	0.02	2019	ITALY
6	0	2020	NORWAY
5	0	2012	NEW ZEALAND

Source: Generated by CiteSpace based on bibliographic data from Web of Science and Scopus (N = 480)

Centrality scores have another story. Spain leads at 0.27, followed by Ireland (0.20) and Indonesia (0.14); these countries are relatively better connectors in the network than would be expected based on their raw number of publications. When grouped by development level, the seven developed countries - the USA, Spain, the UK, Australia, Germany, Ireland and Canada - have a combined centrality of 0.79, and the nine developing countries have only reached 0.31. China is a typical case: although it leads in the number of publications, its centrality of 0.12 suggests that its connector role in the global network is still relatively small. There is a gap between output and influence; although developing countries are producing more research on the digitalisation of PE, developed countries still lead in terms of shaping global knowledge diffusion.

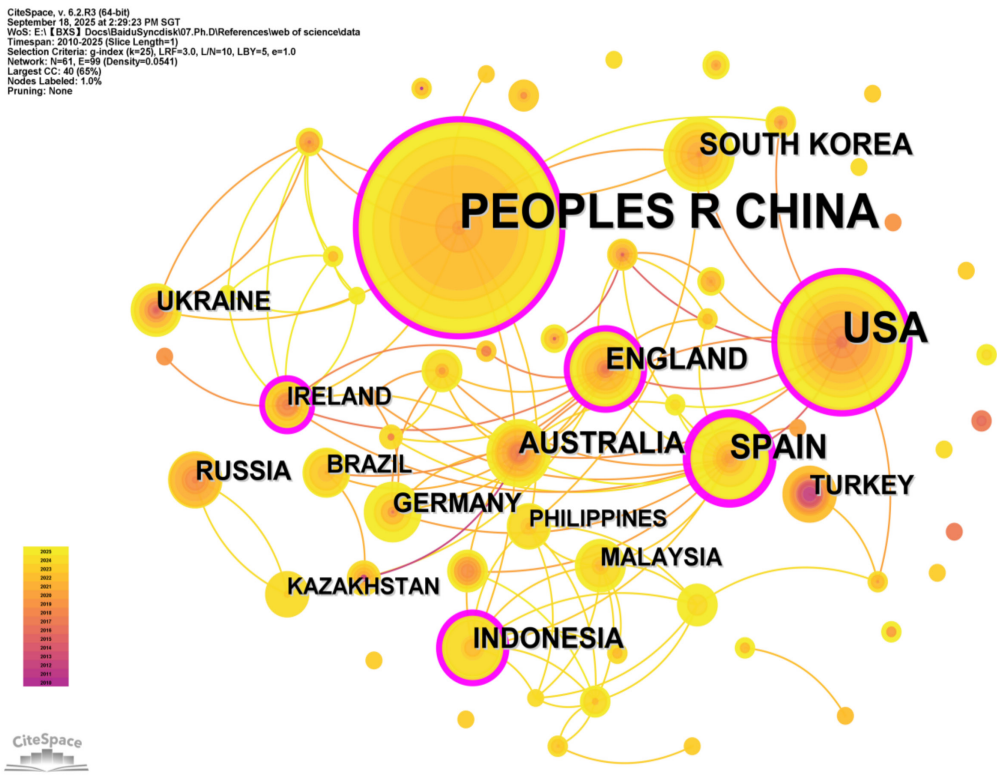

Figure 3. Major Country Collaboration Network

Source: Authors' own visualization generated using CiteSpace (Version 6.2.R4) based on bibliographic data retrieved from the Web of Science Core Collection.

3. Analysis of Institutional Cooperation Networks

A total of 275 research institutions are shown in the institution co-occurrence map, and among them, 217 are linked to form a network with a density of 0.0058. It can be seen that the foundation for institutional

cooperation in this area is relatively weak, and the network of cooperation is loosely connected. As shown in the table, there are 27 institutions that have published more than 3 papers. The Ministry of Education and Science of Ukraine is the highest at 14 publications, followed by Beijing Sport University, Charles Sturt University, Loughborough University, the University System of Georgia, the University of Limerick, and the University of Northern Colorado, all with 5 publications. These institutions have been paying attention to the integration of digitalisation and physical education for some time.

Table 2. Publication Status of Major Institute in This Research Field from 2010-2025

Count	Centrality	Year	Institutions
14	0.01	2015	Ministry of Education & Science of Ukraine
5	0	2018	Beijing Sport University
5	0	2017	Charles Sturt University
5	0	2017	Loughborough University
5	0	2016	University System of Georgia
5	0	2013	University of Limerick
5	0	2017	University of Northern Colorado
4	0	2022	Arizona State University
4	0	2020	California State University System
4	0	2020	City University of New York (CUNY) System
4	0	2023	Deakin University
4	0	2014	Indiana University System

Source: Generated by CiteSpace based on bibliographic data from Web of Science and Scopus (N = 480)

All the main institutions have centrality scores of 0 or very close to 0 (the Ministry of Education and Science of Ukraine is at 0.01). No clear institutional hub has been formed, and the cooperative networks are largely independent of each other. US universities lead in terms of output and have six such institutions, along with European institutions such as the University of Limerick and Loughborough University, and Australia's Deakin University. The fact that the top producers of this research area include a government educational department and a special sports university shows that various parties are involved. In short, the low centrality scores

indicate that inter-institutional cooperation has been initiated at a relatively early stage and still has a long way to go.

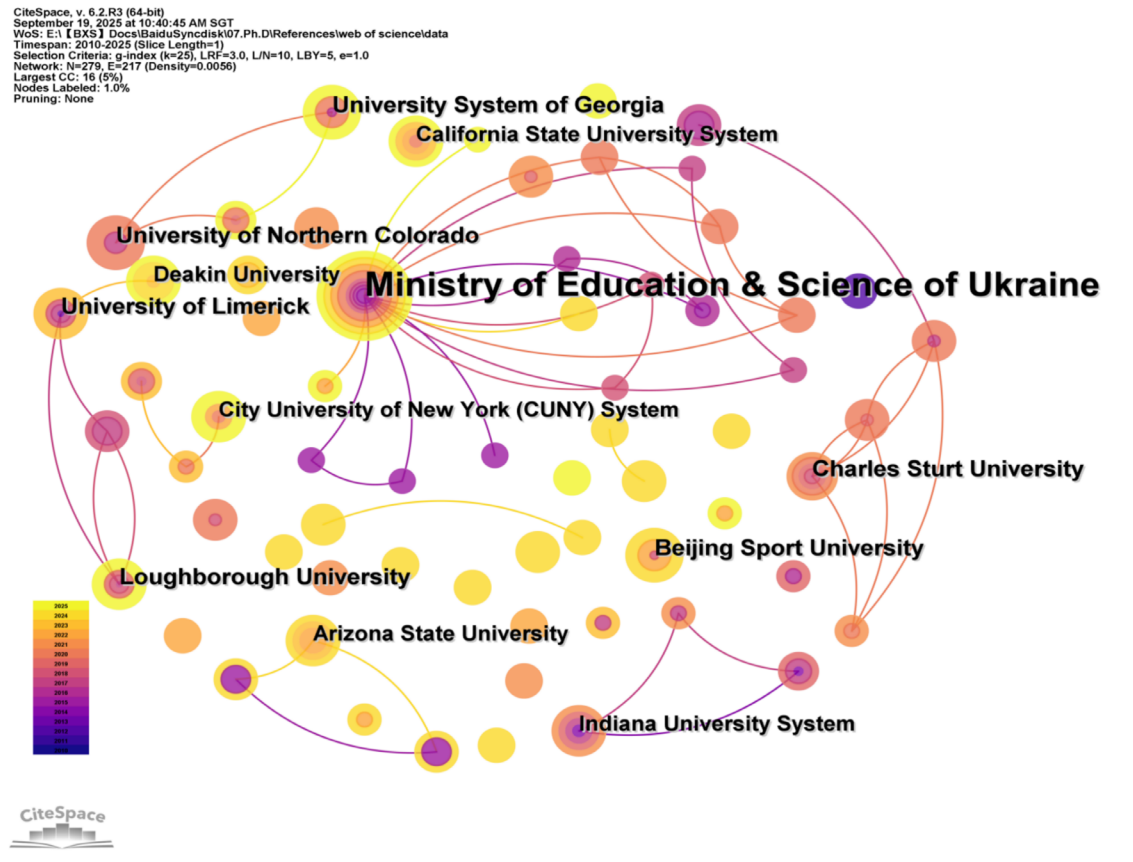

Figure 4. Major Research Institution Collaboration Network in This Research Field from 2010-2025

Source: Authors' own visualization generated using CiteSpace (Version 6.2.R4) based on bibliographic data retrieved from the Web of Science Core Collection.

4. Analysis of Author Cooperation Networks

The author's cooperation network has 340 researchers and 278 collaborative links, resulting in a network density of 0.0048. The low density indicates that there is currently a lack of cooperation among scholars in this field and a large amount of space for development. Based on the data, there are 8 main authors who have published three or more papers. Among them, Casey and Ashley are tied for first with an output of 5 papers each; Wagner, Ingo, Krause, Jennifer M., and Botagariyev, Tulegen have each published 4 papers, and the remaining 4 scholars have each contributed 3 research outcomes.

Table 3. Publication Status of Major Author in This Research Field from 2010-2025

Count	Centrality	Year	Authors
5	0	2017	Casey, Ashley
4	0	2024	Wagner, Ingo
4	0	2017	Krause, Jennifer M
4	0	2024	Botagariyev, Tulegen
3	0	2017	Goodyear, Victoria A
3	0	2020	Calderon, Antonio
3	0	2013	Lei, Ming
3	0	2024	Mambetov, Nurolla

Source: Generated by CiteSpace based on bibliographic data from Web of Science and Scopus (N = 480)

Notably, the centrality metrics of all the main authors in the network are 0. Therefore, there are no prominent academic leaders or collaborative platforms at present for this line of research. Based on the observation of the visualization map, researchers have formed several relatively independent, small-scale collaborative groups, such as the purple collaboration cluster around Mambetov and Nurolla, and the yellow research team led by Botagariyev and Tulegen.

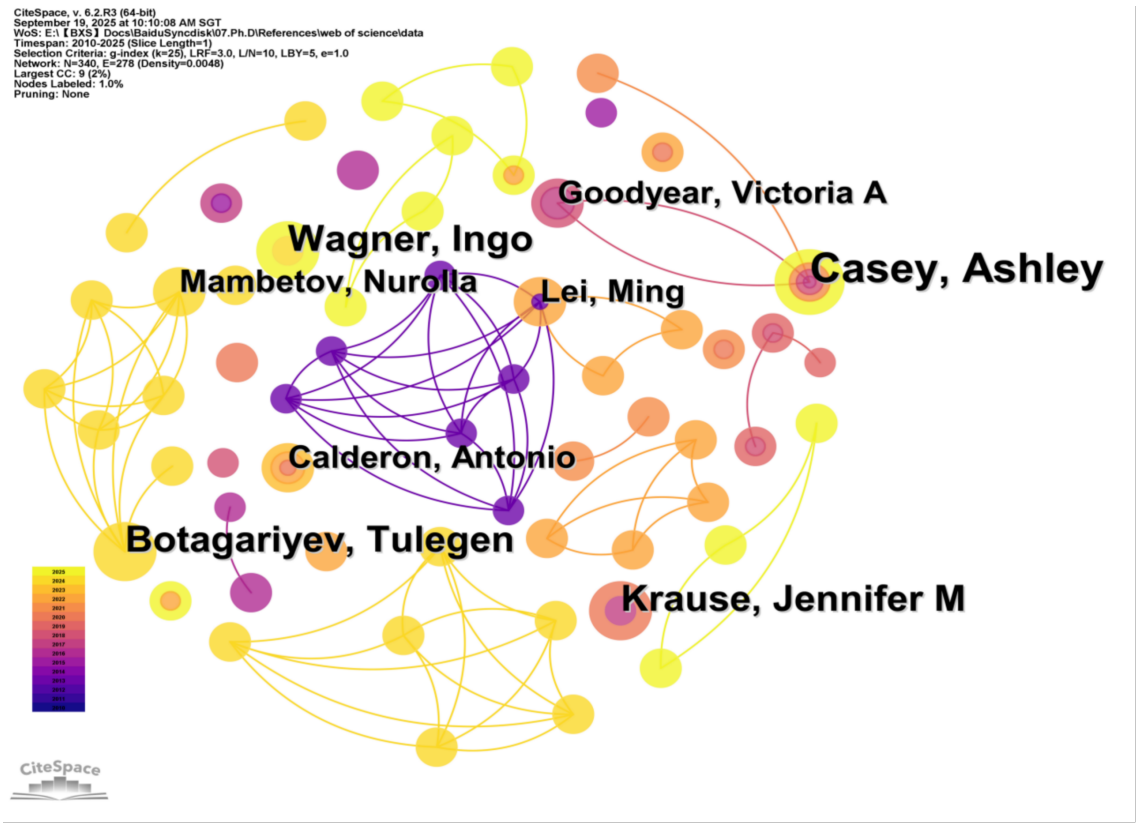

Figure 5. Publication Status of Major AuThor in This Research Field from 2010-2025

Source: Authors' own visualization generated using CiteSpace (Version 6.2.R4) based on bibliographic data retrieved from the Web of Science Core Collection.

The fragmented structure of the author cooperation network reflects the present stage of development for interdisciplinary digital integration in physical education. On the one hand, it shows that the area is relatively new and still developing; on the other hand, more cooperation among all parties and institutions needs to be strengthened to facilitate knowledge integration and theoretical progress. As the research topics are explored in more detail, more scholars will be eager to join, and eventually an organised and strong academic community will be formed.

5. Knowledge Base

In bibliometrics, the knowledge base refers to the body of essential papers that are frequently cited by many other papers in a specific field—these works provide the theoretical and methodological basis for the entire field (Small, 1973; Chen, 2006; Cobo et al., 2011; Aria & Cuccurullo, 2017). Co-citation analysis in this paper has

found some areas where scholars have reached a general consensus.

Most scholars have indicated that digital technology is not inherently good for education, and therefore, whether it can actually help depends on how it is employed. A tool-oriented approach will likely only achieve a superficial result and be confined to data observation out of a desire for observation. If the focus is on instructional objectives and the requirements of learners, then technology can be applied to support personalised learning and precision teaching (Casey et al., 2017; Williamson, 2015). According to the case study, students in the "pedagogy-led" model have performed better than those in the "technology-driven" model (Williamson, 2015).

Based on the research of students, digital tools can motivate them to learn more eagerly in class. Interactive exergames and wearable devices attract less-active students by increasing their enjoyment and providing immediate feedback (Bodsworth & Goodyear, 2017; Jastrow et al., 2022; Lindberg et al., 2016). AI educational robots and blended learning models have also increased students' enthusiasm, and the experimental group consistently outperformed the traditional control group (D.). Yang et al., 2020; J. Yang and others (2025).

Digital technology has helped to change the learning outcome model of Physical Education into a closed-loop system that covers pre-class resource distribution, in-class real-time communication and post-class data feedback (Müller & Wagner, 2025; D.). Yang and others (2020); Zhong and others (2025). The three types of power are: physical capability, knowledge and values, and emotional expression. Based on the above studies, several data sources have been employed to improve the accuracy of the evaluation by about 30% (Jastrow et al., 2022; Müller & Wagner, 2025). Video feedback is employed to teach skills in sports such as gymnastics and basketball, and interactive exercise games can be used to improve cardiorespiratory endurance and balance (Jastrow et al., 2022; Lindberg et al., 2016; Wallace et al., 2023). Together, VR and IoT can provide immersive simulations and real-time data analysis to expand the scope of personalised teaching and movement correction (Ding et al., 2020; Zhong et al., 2025).

There are still some deficiencies. Lack of Teacher Digital Literacy is the most frequently mentioned bottleneck. Most teachers are still at the level of fragmented tool use and do not integrate technology with teaching in an effective way (Østerlie et al., 2025; Wallace et al., 2023). This suggests that the teachers have not received regular training, and they are reluctant to change due to cognitive habits; research has shown that PE teachers generally make teaching decisions based on intuition rather than careful thought, resulting in a status quo bias and low self-efficacy in using technology (Müller & Wagner, 2025; Wyant & Baek, 2019).

AI and intelligent platforms can improve the efficiency of assessment and feedback in the area of teacher-student relationships, but they cannot replace teachers in other areas such as emotional interaction, value guidance, and the cultivation of sportsmanship (Lee & Lee, 2021; Wallace et al., 2023; D. Yang and others (2020). A "human-machine complementarity" model, which supports teachers in using technology, is likely to be more feasible.

In terms of resource equity, more than 20% of student groups still lack access to good digital support, and cross-regional differences in resource distribution are still noticeable (Fröberg & Lundvall, 2021; J.). Yang and others (2025). Ethical concerns are also increasing: data privacy breaches, algorithmic bias and risks to body

image have been occurring regularly in practice, and there are calls for institutional-level ethical norms and safeguard mechanisms (Østerlie & Killian, 2025; Jastrow et al., 2022; Fröberg & Lundvall, 2021).

Finally, the scope of the existing research is relatively narrow. Around 79% of the literature is in Chinese, and about 80% of it focuses on higher education; K-12 and special education are less frequently covered. Most studies are short-term intervention designs, and their long-term effects of digital PE have not been studied (Zhong et al., 2025). Cross-national comparisons also show a divergence: Western countries generally focus on AI and blended learning, while in China, the implementation is still mainly at the tool level; Japan has been integrating digital technology with traditional physical education in a culturally appropriate manner (Saiz-González et al., 2025; Williamson, 2015). Therefore, the various patterns suggest that the digitalisation of PE is multifaceted and context-specific, not uniform.

6. Summary

Different Teaching Methods have different actual results when applying digital technology. Some studies have shown that it can motivate students to study more and better. However, a deficiency in teachers' digital literacy is also a problem to be addressed. Technology can increase efficiency and provide personalised learning, but it is not suitable to replace teachers entirely at this time. In addition, problems of unequal distribution of educational resources and the digital divide are still serious; at the same time, most previous studies have been limited in scope, region and time. At the same time, there are problems of ethics and fairness. Cross-national practices have shown various levels of development and differentiation. The above consensus has provided a strong foundation for research on digital applications in physical education and has also pointed out directions for future deepening of theoretical construction and continuous practical innovation.

III. Visual Analysis of Research Hotspots in Digital Physical Education

1. Keyword Co-occurrence Analysis

A total of 378 nodes and 1,547 links were obtained from the keyword co-occurrence network in CiteSpace, and the entire network density was 0.0217. The top word in the network is "physical education", which appears 124 times and has a centrality of 0.39. Thus, PE serves as the basic topic of this area of study. The two closest subject keywords are "students" (frequency: 47, centrality: 0.14) and "teachers" (frequency: 25, centrality: 0.08); therefore, the research subjects are mainly students and teachers. In addition, "children" (frequency: 22; centrality: 0.11) is also relatively frequent, and research has been carried out at all levels of education.

Table 4. Keywords with Frequency >10 in This Research Field from 2010-2025

Count	Centrality	Year	Keywords
124	0.26	2010	physical education
47	0.06	2016	students
37	0.06	2020	artificial intelligence
36	0.09	2013	digital technology
31	0.03	2016	technology
30	0.15	2013	social media
30	0.07	2012	performance
29	0.09	2016	health
25	0.13	2012	teachers
22	0.14	2016	children
22	0.05	2019	physical activity
19	0.04	2020	virtual reality
18	0.29	2016	motivation
17	0.33	2016	challenges
14	0.08	2016	impact
13	0.07	2020	Augmented reality
12	0.06	2015	ICT
11	0.1	2015	professional development
11	0.03	2022	perceptions

Source: Generated by CiteSpace based on bibliographic data from Web of Science and Scopus (N = 480)

Several high-frequency terms, such as "physical education", "students", "digital technology" and "artificial intelligence", were included in the original search query, so their prominence is expected. The significance of these words lies in their connections to other words in the network. "Physical education" frequently appears

with "performance", "health" and "motivation", indicating that research has broadened to address motivation, health promotion and educational values in addition to instruction. "Digital technology" serves as a bridge word that connects the macro-level concept of "ICT" with new tools such as "social media" (30 times, 0.17), "virtual reality" (19 times, 0.09), and "augmented reality" (13 times, 0.04), thereby demonstrating the trend of informatisation towards intelligent and immersive teaching models.

Given that the frequent words in the text include "performance", "health", "motivation" and "impact", it can be inferred that this study investigates the effect of digital tools on athletes' results, health and learning attitudes. At the same time, terms such as "challenges", "perceptions" and "professional development" indicate that there are ongoing problems with implementation, subjective experiences of teachers and students, and the required professional ability for technology to function in practice.

2. Keyword Clustering Analysis

CiteSpace generated 18 clusters from the keyword data, with cluster sizes between 5 and 33, and most had Silhouette values greater than 0.879 (the highest being 0.998). These are relatively high, so the clusters have strong internal consistency and are well-separated. Together, the clusters show that the research has moved from asking "whether to use technology" to more specific questions about how technology works, in which environments it is effective, and what it means for different groups of learners.

The main thread in the clusters is the integration of technology and physical education. The first clusters that were formed around "digital technology" and "social media" have now been replaced by new ones focusing on "artificial intelligence", "virtual reality" and "generative AI", and it can be seen that changes in technology have led to new research directions at a faster rate. Clusters around "technology integration" and "educational innovation" indicate that the problem of how to integrate technology in physical education, rather than whether it can be applied, is a focus of research.

The second is the line of instruction and teacher education. Clusters with "pedagogy" and "teacher education" focus on the professional roles required to use digital tools effectively in teaching; those centered on "physical activity", "adolescents" and "youth" connect technology application with the physical and developmental needs of specific student groups.

The third is a thread for multi-scenario and cross-domain extensions. Clusters related to "online learning" and "blended learning" are manifestations of digital technology's application in distributed education, and clusters in "public health" and "sports journalism" show how PE digitalisation has spread to other areas.

In short, the cluster structure indicates that the three main directions for research in digital PE are: educational benefits focused on performance, health and motivation; technical applications involving digital technology, AI and immersive tools; and contextual challenges such as teacher development, student perception and integration barriers. "Digital technology" is a key word that connects educational needs with the entire range of available technological means as a link node.

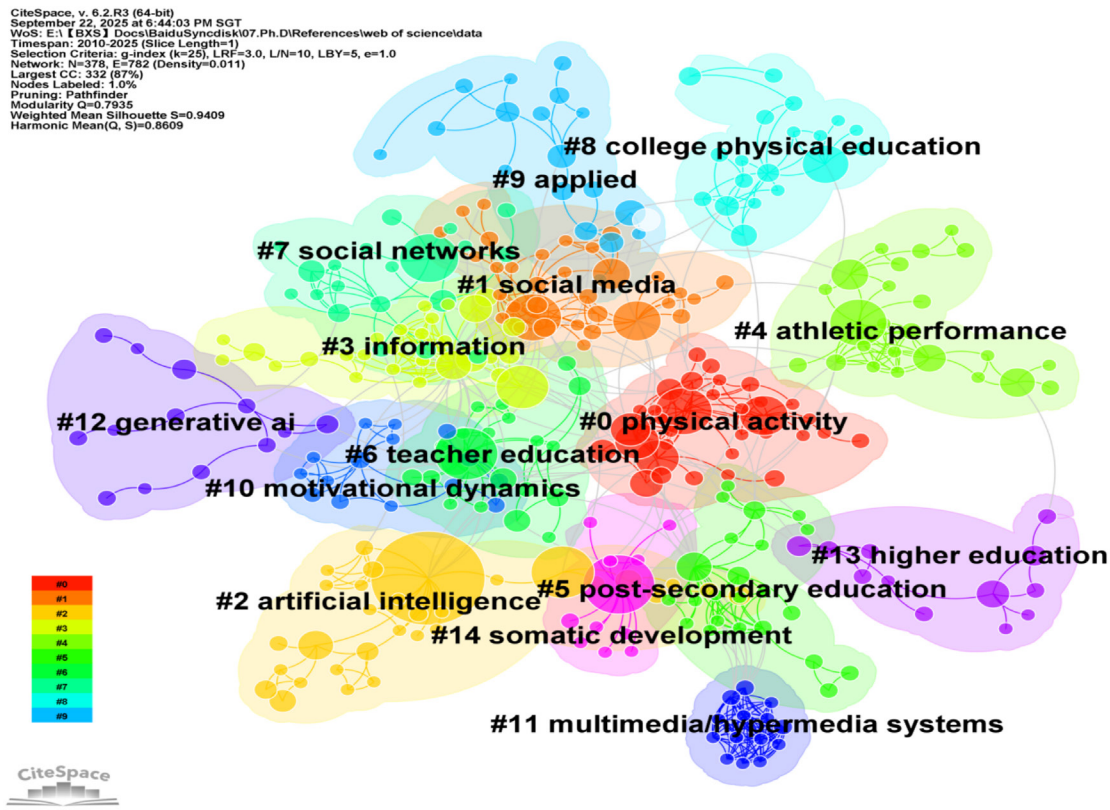

Figure 6. Keyword Clustering Map in This Research Field from 2010-2025

Source: Authors' own visualization generated using CiteSpace (Version 6.2.R4) based on bibliographic data retrieved from the Web of Science Core Collection.

3. Summary

Based on the visualisation analysis of the keyword co-occurrence network and clustering structure presented by CiteSpace, this paper will systematically present the main thematic structure and hotspot distribution characteristics of research in digital physical education. In short, a multi-dimensional knowledge network has been constructed around "physical education", and key terms such as "students", "teachers", "digital technology", and "artificial intelligence" serve as core supports. The research subjects mainly include two core parties: students and teachers, and the research environment is mainly concentrated in higher education; therefore, it is relatively far from other educational levels and application scenarios.

Based on the results of keyword co-occurrence analysis, the hotspots in digital PE research are not only technologies but also fundamental educational values that digital technology can provide to athletic performance, physical health, learning motivation and teaching efficiency. It can be seen that the research focus

has gradually shifted from the early stage of "technological introduction" to the exploration of "technological application effects and educational significance". At the same time, the appearance of keywords such as "challenges", "perceptions", and "professional development" indicates that the academic community has begun to systematically address the practical obstacles in digital implementation, the subjective experiences of teachers and students, and the supporting conditions for the professional development of teachers. Therefore, it can be inferred that research topics are moving away from the earlier period of technological optimism and becoming more rational and deliberate.

Keyword clustering analysis can also be performed on the research hotspots in this area to understand their internal structure and themes. In general, the hotspots in research on digital Physical Education (PE) are concentrated in three interconnected directions: first, the application of frontier digital technologies such as AI, VR and AR; this reflects the continuous driving force of technological iteration in research topics; second, research on instructional practice and teacher development focused on pedagogy, teacher education and technology integration; this focuses on the feasibility and effectiveness of embedding technology in instructional contexts; and third, holistic education goals and cross-domain extensions focusing on physical activity, health promotion and various learning scenarios; this reflects the spillover effects of digital PE in public health, online and blended learning. The high Silhouette values of all the clusters indicate that the current research topics have good focus and a strong foundation in academia.

In short, the research hotspots in digital PE exhibit a structural feature of "continuous technological upgrading – deepening of instructional practice – expansion of educational value". This pattern can both respond to the development of new technologies such as AI and be grounded in the instructional goals and educational functions of physical education. The hotspot landscape shown above is the general knowledge structure of this area, and it can provide strong support for studying the development path and leading-edge changes of this area over time, thus offering a foundation for trend analysis in Chapter 4.

IV. Visual Analysis of Research Trends in Digital Physical Education

1. Analysis of Keyword Time-Zone Knowledge Map

CiteSpace shows the development of knowledge over time in the form of a time-zone view. Each keyword is linked to a time zone according to the year of its first appearance, and the links among nodes and their thickness show how often and in what context keywords co-occur over time. This function can show the changes in research topics and the development logic of the knowledge system. Based on the time-zone map of the research field for digital physical education (Figure X) and keyword data, the evolution of research can be divided into three periods: the first exploration period (2010-2015), the period of rapid development (2016-2020), and the current period of diversified innovation (2021-2025).

1.1 Initial Exploration Phase (2010–2015)

At this time, digital PE had entered the academic discussion, and research began to focus on the early integration of traditional physical education and basic digital tools. "Physical Education" was the main reference point, and early digital keywords such as "Internet", "social networks", "digital technology" and "social media" started to appear, showing that scholars were beginning to explore how PE connected with new technologies. "Beliefs", "attitudes" and "acceptance" referred to people's awareness of how teachers and students were responding to digitalisation, while "teachers" and "competence" raised issues concerning the teachers' professional readiness. By around 2015, keywords such as "ICT" and "pedagogical content knowledge (PCK)" indicated a change in focus: instead of asking whether digital technology should be introduced to physical education, people began to inquire about how to effectively combine the two, and thus more applied studies started.

1.2 Rapid Development Phase (2016–2020)

At this time, the integration deepened and the scope of research expanded. Frequently appearing words are "students", "technology", "motivation", "impact" and "physical activity"; thus, the subject of discussion has moved from technology to its effect on learners and exercise. The appearance of terms such as "digital divide" and "challenges" indicates that attention has been drawn to the implementation gap; at the same time, a large number of keywords related to new technologies, including "artificial intelligence", "virtual reality" and "augmented reality", suggest that the frontier tools have begun to be applied in PE research. "Academic performance" and "distance education" also show that the field has expanded to cover blended and remote learning, a trend that accelerated significantly around 2020 due to the pandemic. The first two goals of this stage were to verify feasibility and to examine the actual operating conditions.

1.3 Diversified Innovation Phase (2021–2025)

Recently, there have been many themes and new ways of study. The keywords "perceptions", "online learning", "pedagogy" and "knowledge" suggest that researchers have been exploring how the digital environment has changed the logic of teaching and subject experience. "Generative AI", "wearable technology" and "real-time feedback" are examples of specific applications, such as using wearables to collect real-time motion data or applying generative AI to design instruction. Systematic reviews and meta-analyses have been proposed to demand a relatively high level of methodology for comparable and aggregated data. "Student engagement", "risk" and "digital competence" are all new dimensions that have emerged in research on the experience of learners and digital safety. By 2025, keywords such as "experiential learning" and "AI disclosure" indicate that the scope of the field has expanded to include ethical issues and transparency; thus, research has moved beyond the stage of tool adoption and entered a period of more reflective, systemic inquiry.

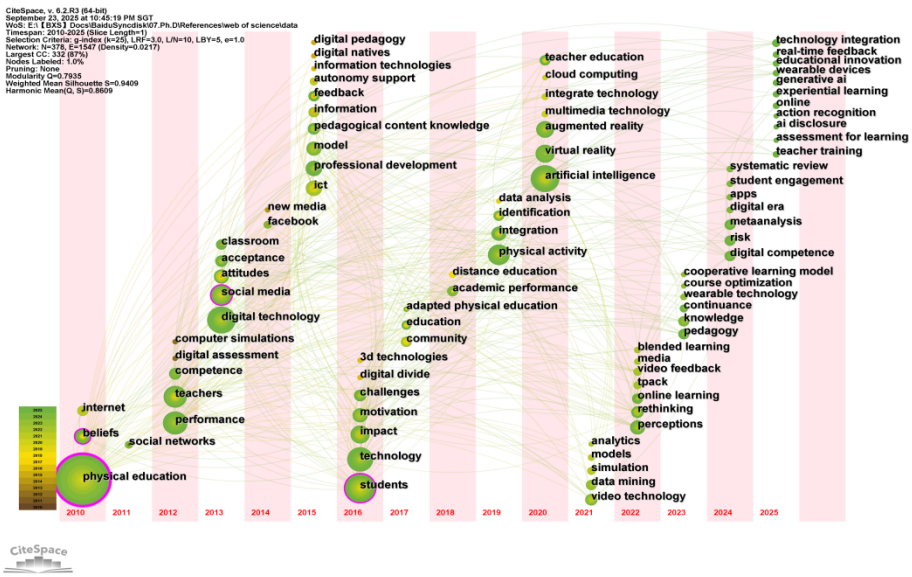

Figure 7. Timeline Distribution Map of Keywords in This Research Field from 2010-2025

Source: Authors' own visualization generated using CiteSpace (Version 6.2.R4) based on bibliographic data retrieved from the Web of Science Core Collection.

2. Analysis of Keyword Burst Knowledge Mapping

Keyword burstness refers to a relatively high-frequency period of a word that indicates a change in research focus and the beginning of a new research trend. CiteSpace burst detection of the digital PE literature shows three distinct stages of development.

Phase 1: Exploration of Basic Information Tools (2010-2015). Burst terms at this time are "internet", "multimedia", "video" and "information technology"; they indicate that research has shifted to exploring new means for delivering PE teaching. The first two applications of "game" (gamification) were relatively prominent, so it can be assumed that researchers had already begun to explore how to motivate students in physical education through active video games. The first type was technology-assisted instruction; digital tools are employed to expand teaching resources and overcome the drawbacks of traditional physical education teaching, such as the transience of demonstrations.

Phase 2: Growth of Instructional Model Transformation and Blended Learning (2016-2020). Burst terms in this stage are "blended learning", "adoption", "active video game" and "COVID-19", and they indicate a move from the use of isolated tools to deeper integration of teaching and learning. The emergence of "blended learning" indicates that the new mode will combine online teaching and offline practice of skills. The recent focus on TAM-based studies of technology acceptance has also been reflected in the trend of "adoption". The high-intensity burst of "COVID-19" in 2020 was the most disruptive event in recent times for the field, and

global PE instruction was forced to use digital means as its main way, not just as an addition. This large-scale emergency exercise provided a basis for the normalisation of digital PE that followed.

Phase 3: Deepening Intelligent and Precise Teaching (2021-2025). Since 2023, the burst terms have been increasingly technological in nature; at present, the research frontlines include "artificial intelligence", "machine learning", "deep learning" and "computational thinking". At present, the main direction is no longer the digitisation of resources but rather intelligent processing of data; for example, computer vision is used for motion capture and correction, machine-learning algorithms recommend personalised exercise plans, and data-driven methods evaluate the effectiveness of learning. The rise of "mental health" is also noteworthy; thus, digital Physical Education is now extending its scope to cover psychological well-being and is demonstrating an increased interest in integrating the mind and body in education.

Over the entire period from 2010 to 2025, international research on the digitalisation of physical education has shown a trend of development: first appearing as "Internet + Sports Resources", followed by reconstructions of instructional models in blended learning, and now reaching the forefront with AI-driven personalised teaching.

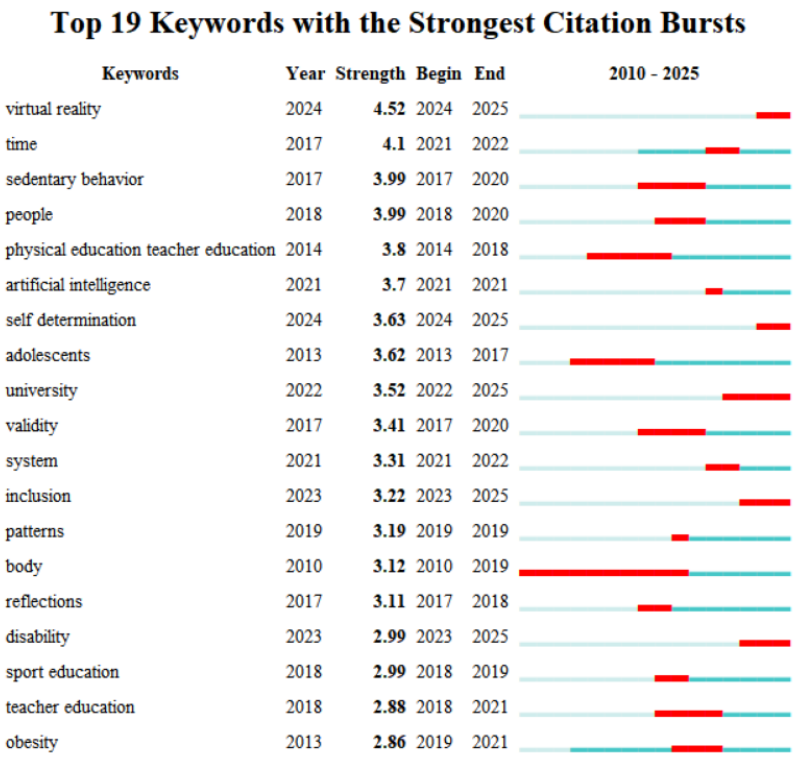

Figure 8. Keyword Burst Detection Map in This Research Field from 2000-2025

Source: Authors' own visualization generated using CiteSpace (Version 6.2.R4) based on bibliographic data retrieved from the Web of Science Core Collection.

3. Summary

Quantitative analysis of the keyword co-occurrence network shows that international research on the digitalisation of physical education has formed a dense academic network with "Physical Education" at the centre, and it is mainly supported by "Digital Technology", "Higher Education" and "Students". The distribution of high-frequency keywords and high-centrality nodes indicates that the research focus in this field has shifted from individual technological applications to a multi-dimensional integration ecosystem of "Technology-Pedagogy-Human". However, keyword co-occurrence primarily shows the static structure and association strength of research hotspots and is unable to fully reflect the evolution trajectory or the rise and fall of various research themes over time. To expand the research scope of digital PE over time and to identify new trends that may develop in the future, burstiness analysis can be used to add a time dimension. Thus, the following will be the subject of our discussion: the development stages and front-line trends of this region.

V. Conclusion and Discussion

1. Summary

Using CiteSpace for knowledge mapping of the 480 publications in the Web of Science Core Collection and Scopus (2010-2025), this paper has systematically studied the development of digital physical education abroad in four aspects: research situation, knowledge base, hotspot structure, and evolutionary trend.

Digitally augmented PE research started slowly but has increased at an accelerated pace recently. The 2010-2015 period focused on tool introduction and feasibility studies; 2016-2019 showed a growing interest in specific application models and instructional effectiveness; and since 2020, due to the pandemic and progress in AI, both the number of publications and the scope of topics have expanded significantly. Collaboration networks at the country, institutional and author levels all show the same pattern: active publication output but fragmented ties, and no stable international core has been formed yet.

Co-citation analysis in the knowledge base shows that most scholars agree on some points. The purpose of education for new technologies is not the technology itself. Empirical evidence consistently shows that digital tools can motivate and engage students in learning, and they have also been applied to create a data-driven pre-class, in-class and post-class loop for physical education. At the same time, teacher digital literacy gaps, weak technology-pedagogy integration, uneven resource distribution, and ethical problems are also main constraints on further development.

The three research hotspots are: application of digital technology (AI, VR, AR, wearables); instructional practice and teacher development (pedagogical innovation, teacher education, technology integration); and educational benefits and holistic goals (athletic performance, physical health, motivation, diverse learning scenarios). These directions are related, and the whole field is shifting from a single technological focus to a

"Technology-Pedagogy-Human" approach.

Over time, the three periods of the field have been basic information tools supporting teaching; blended learning and instructional model changes; and finally, AI-driven precision and intelligent teaching. Sustained increases in the frequency of "generative AI", "learning analytics", "real-time feedback" and "digital literacy" suggest that research is now focused on extending technological application to instructional decision support, learning experience design, and competency cultivation.

2. Discussion

According to the systematic review of the current research status, hotspot structure and evolutionary trends in digital physical education have been identified; thus, more work needs to be done at both the theoretical and practical levels based on these results. The theoretical basis and practical value of digital PE research will be introduced here, along with limitations and future directions of the research, as well as a summary of existing consensus.

2.1 Theoretical Insights of Digital PE Research

First, the study supports the idea that technology is not the cause of better educational results. Both keyword analysis and the knowledge base consistently show that AI, VR and wearable devices have gained attention in research not due to their technical difficulty but because of how well they can be integrated into teaching and learning, as well as student development. Therefore, the direction of research has changed from focusing on tools (instrumental rationality) to focusing on goals in education (educational rationality); it now asks what good teaching requires.

Second, according to the above results, the teacher serves as the mediator. Whether visible in clusters around teacher education and professional development, or in repeated references to digital literacy gaps in the knowledge base literature, teachers have emerged not as passive recipients of digital reform but as the key subjects for translating technological ability into teaching effectiveness. Provide a direct theoretical foundation for models that consider teacher digital competence as a mediator or moderator.

Third, in recent years, the focus of the field has shifted from technology application to learning experience and instructional decision support. The high frequency of terms such as "student engagement", "digital literacy" and "learning analytics" indicates that at present, researchers are investigating why, for whom, and under what circumstances technology can be effectively applied. Therefore, the direction of research will include mechanism analysis, moderator studies and context-specific research designs.

2.2 Implications for Practice and Policy

The direction of technology adoption in Physical Education should be the teaching goal, not the purchase

of equipment or construction of platforms. Only when these digital tools are used to achieve specific teaching objectives, such as providing motion feedback, motivating students, or offering individualised instruction, will they have teaching value; otherwise, they will be little more than a new-technology exhibition.

Enhance the Policy Goals to Strengthen Teacher Professional Development. All previous research has shown that a lack of digital literacy, fear of technology and low self-efficacy are all associated with poor application outcomes. Good support should be continuously provided and tailored to the specific circumstances of the teaching staff to help them apply new-media literacy in their teaching.

Equity and Ethics should be accompanied by efficiency. At present, the problems of the digital divide, data-privacy risks and algorithmic bias are serious and limit the scope of digital public services. Administrators and policymakers need to create protective norms and institutions at the institutional level to prevent further harm or deterioration of the existing inequalities in the digital reform.

2.3 Research Limitations and Future Directions

This paper will outline the research system and trend of research, but not how technology is applied in particular teaching environments. The literature reviewed mainly consists of English-language journals, and thus may lack practice and experiments conducted in non-English-speaking environments.

Future work will address the above deficiencies by conducting teacher-centered empirical studies on the interplay of digital competence, technostress and instructional beliefs; extending longitudinal research designs to track the long-term effects of digital interventions; carrying out cross-cultural comparative studies to explore how educational systems and cultural contexts influence different trajectories of digital PE; and paying close attention to ethics, safety and psychological impact, ensuring that efficiency gains in digital PE are accompanied by a commitment to humanistic values and sustainable development.

Digital PE is not an easy-to-achieve technology improvement. It is all-encompassing; thus, it will change the idea of education, teacher quality, students' lives and school management. Technology should only be used to support high-quality physical education, and its foundation should be pedagogy, teachers' judgment and students' growth.

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