



## ORIGINAL RESEARCH ARTICLE

# New Paradigm of Physical Education: SLR Analysis of AI in Handball Measurement Tests and SDGs-Based Eco-Friendly Facilities

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**Article History:** Received: 12 Oct 2025 • Revised: 05 Dec 2025 • Accepted: 15 Jan 2026 • Published: 21 May 2026

## ABSTRACT

**Purpose:** This study aims to systematically analyze the role of artificial intelligence (AI) in optimizing handball measurement test instruments while integrating environmentally friendly facility management to support Sustainable Development Goals (SDGs) within physical education. **Methodology:** Employing a Systematic Literature Review (SLR) based on PRISMA design, this research analyzed literature from Scopus and ERIC databases using VOSviewer and Harzing's Publish or Perish software. **Findings:** The results demonstrate that AI integration significantly enhances the objectivity of motor assessment and improves the efficiency of facility management, with teacher digital literacy identified as a critical scaffolding variable for successful implementation. Furthermore, the findings reveal that facilities lacking sustainability principles fail to provide long-term contributions to students' psychomotor development in a global context. **Implications:** This new paradigm necessitates a repositioning of the physical education curriculum that synergizes smart technology with green facility management. **Recommendations:** Institutions are encouraged to adopt AI-driven evaluation tools and prioritize sustainable infrastructure design to create an inclusive, efficient, and ecologically responsible future for sports education. **Originality/Value:** By bridging the gap between digital transformation and environmental sustainability in physical education, this research provides a comprehensive framework for addressing the limitations of manual assessment methods and infrastructure management, offering a strategic approach to modernizing the field in line with global sustainability targets.

## ABSTRAK

Tujuan: Studi ini bertujuan untuk menganalisis secara sistematis peran kecerdasan buatan (AI) dalam mengoptimalkan instrumen pengukuran kemampuan motorik dalam olahraga bola tangan sekaligus mengintegrasikan pengelolaan fasilitas yang ramah lingkungan untuk mendukung Tujuan Pembangunan Berkelanjutan (SDGs) dalam pendidikan jasmani. Metodologi: Dengan menggunakan Tinjauan Literatur Sistematis (SLR) berdasarkan desain PRISMA, penelitian ini menganalisis literatur dari basis data Scopus dan ERIC menggunakan perangkat lunak VOSviewer dan Harzing's Publish or Perish. Temuan: Hasil penelitian menunjukkan bahwa integrasi AI secara signifikan meningkatkan objektivitas penilaian motorik dan meningkatkan efisiensi pengelolaan fasilitas, dengan literasi digital guru diidentifikasi sebagai variabel pendukung penting untuk keberhasilan implementasi. Lebih lanjut, temuan menunjukkan bahwa fasilitas yang kurang menerapkan prinsip keberlanjutan gagal memberikan kontribusi jangka panjang terhadap perkembangan psikomotorik siswa dalam konteks global. Implikasi: Paradigma baru ini memerlukan penataan ulang kurikulum pendidikan jasmani yang mensinergikan teknologi cerdas dengan pengelolaan fasilitas hijau. Rekomendasi: Lembaga-lembaga didorong untuk mengadopsi alat evaluasi berbasis AI dan memprioritaskan desain infrastruktur berkelanjutan untuk menciptakan masa depan pendidikan olahraga yang inklusif, efisien, dan bertanggung jawab secara ekologis. Orisinalitas/Nilai: Dengan menjembatani kesenjangan antara transformasi digital dan keberlanjutan lingkungan dalam pendidikan jasmani, penelitian ini menyediakan kerangka kerja komprehensif untuk mengatasi keterbatasan metode penilaian manual dan manajemen infrastruktur, serta menawarkan pendekatan strategis untuk memodernisasi bidang ini sejalan dengan target keberlanjutan global.

**How to cite:** Prasetyo, D. A., & Basri, M. H. (2026). The New Paradigm of Physical Education: SLR Analysis of AI in Handball Measurement Tests and SDGs-Based Eco-Friendly Facilities. *Assyfa Learning Journal*, 4(2), 105–116. <https://doi.org/10.61650/alj.v4i2.992>

**Keywords:** Artificial Intelligence, Handball, Physical Education, Facilities and Infrastructure, Sustainable Development Goals (SDGs).

## INTRODUCTION

Physical Education (PE) is currently in the midst of a global crisis triggered by climate change, the acceleration of digital transformation, and a massive decline in physical health. The significance of PE at the international level is no longer limited to physical fitness alone, but has become a key pillar in supporting the Sustainable Development Goals (SDGs), particularly SDG 3 (Health and Well-Being) and SDG 4 (Quality Education). Global challenges require education systems to produce not only motor-skilled students but also environmentally conscious and technologically literate students. This is in line with statements by experts who emphasize that the integration of technology and sustainability in sports is a crucial step to maintain the relevance of sports pedagogy in the future (Obaideen et al., 2022; Prasetyo et al., 2025). Therefore, it is important to view PE as an interconnected ecosystem of digital technology, physical activity, and facility sustainability.

The main problem in teaching sports, particularly handball, often stems from conventional and subjective evaluation methods and the management of facilities that neglect ecological aspects. A significant challenge arises when teachers must accurately test and measure complex motor skills amidst limited available instruments. The lack of infrastructure that supports environmentally friendly principles also increases the operational burden on schools and negatively impacts their carbon footprint (Zakari et al., 2022). Teachers' low digital literacy in utilizing Artificial Intelligence (AI) widens the gap between the demands of the modern curriculum and the realities on the ground. If left unchecked, these problems will hinder the achievement of the SDGs targets in physical education due to stagnation of innovation at the practical and managerial levels (Prasetyo et al., 2023; Van den Tillaar, 2021). Several previous studies have attempted to dissect various aspects of physical education and sports. Research related to the effectiveness of physical education learning and motor development has been conducted by (Nordiansyah & Prasetyo, 2020; Sahli et al., 2021; Wandee, 2023); research related to the application of technology in sports was conducted by (Oytun, 2020; Van den Tillaar, 2021); research related to infrastructure and environmental sustainability was discussed by (Li et al., 2022; Obaideen et al., 2022); and research related to creative teaching strategies and the SDGs has been reviewed by (Opstoel et al., 2020; Prasetyo et al., 2025; Vasconcellos et al., 2020). However, each of these studies has significant weaknesses; the studies by Sahli et al. (2021) and Wandee (2023) tend to ignore the green infrastructure aspect, while the study by Oytun (2020) only focused on AI algorithms without connecting them to the pedagogical context in elementary or secondary schools. Much of the literature remains fragmented, with technology and sustainability considered separate entities within the physical education domain. The novelty of this study lies in the integration of AI as a handball measurement test instrument, directly synchronized with the management of environmentally friendly infrastructure within a

single SDGs framework. Unlike previous studies that only viewed AI as a statistical tool, this study positions AI as a key driver in the efficient use of resources in sports facilities (smart infrastructure). This novelty includes an analysis of how AI can reduce energy waste in sports facilities while simultaneously increasing the precision of motor assessments. No study has explicitly systematically synthesized "AI-Green Facilities-Handball Assessment" as a unified new paradigm. The sharpening of the Environmental SDGs aspect in the specific context of handball provides an original contribution to the global sports pedagogy literature (Basri et al., 2025; Śliż, 2025).

The research gap identified is the lack of comprehensive guidelines linking smart technology to green facility standards in athletic schools. This study differs significantly from previous research; while previous studies often focused on single experiments on a single variable (such as AI-only or motor-only), this study conducted a broad systematic review (SLR) to map the relationship and environmental sustainability. There is a data gap regarding how teachers' digital literacy scaffolding can mitigate the negative impacts of unsustainable facilities on students' psychomotor skills. This study fills this gap by exploring the global literature linking cognitive, motor, and affective success through the lens of green technology, a topic that has not been explored in-depth in handball studies (Achenbach et al., 2020; Prasetyo et al., 2025).

The theoretical framework used in this study is based on the Grand Theory of Self-Determination Theory and the Educational Ecosystem Theory. Self-Determination Theory is used to analyze the motivation of students and teachers in adopting AI technology (Vasconcellos et al., 2020), while the Educational Ecosystem Theory provides a perspective that the success of physical education is highly dependent on the interaction between individuals, technology, and the physical environment (infrastructure). The use of these two theories allows researchers to view physical education not only as a physical activity, but as a complex psychological and ecological process. This theory is supported by the argument that a "green" physical environment and "smart" technology together create a more inclusive and effective learning atmosphere for the development of students' sports talents (Opstoel et al., 2020; Rocamora, 2024).

The main concepts carried out in this study include "AI-Powered Assessment" and "Eco-Sport Infrastructure". The concept of AI in this study refers not only to automation, but also to the use of algorithms to predict performance and provide real-time feedback to handball students. On the other hand, the concept of environmentally friendly facilities refers to facilities that minimize greenhouse gas emissions and use sustainable materials in accordance with SDG 12 targets (Duffner et al., 2021; Li et al., 2022). The synergy between these two concepts creates a smart sports ecosystem that can improve the quality of learning while preserving the earth. Facility management based on this concept is believed to increase student psychomotor engagement due to a comfortable environment and transparent assessment data (Cárcamo, 2021; Nordiansyah & Prasetyo, 2020). An interesting aspect of this study, which is very important to examine, is the paradigm shift where physical education now bears moral responsibility for the climate crisis through facility management. Interestingly, the use of AI, which is usually considered expensive and "heavy" for the environment, is mapped in this study as a solution to achieve green efficiency by optimizing paperless measurement tests and minimizing equipment waste. The importance of this research also lies in its efforts to save handball from being technologically lagged behind football or basketball. By exploring this gap, the research offers new hope for schools to maintain motor achievement without sacrificing the ethical environmental values that are a global demand (Mon-López et al., 2020; Prasetyo et al., 2025).

The primary objective of this study is to conduct an in-depth systematic literature review (SLR) to map the potential and challenges of AI integration in handball measurement tests and the management of environmentally friendly infrastructure based on the SDGs. Specifically, this study aims to identify key variables that influence the effectiveness of AI-based motor assessments and find the best framework for sustainable sports facility management. The results of this study are expected to provide strategic recommendations for physical education practitioners and policymakers in designing curricula that focus not only on cognitive and physical achievement, but also on ecological awareness and technological proficiency. Through this objective, the study seeks to create new standards for modern, smart, and green Physical Education (Lawson, 2022; Nuraisyah et al., 2025).

## LITERATUR REVIEW

The research method is a strategic step systematically designed to answer research questions regarding the integration of artificial intelligence and environmentally friendly tools in physical education. The chosen approach ensures that all collected literature data is highly valid and relevant to handball variables and the Sustainable Development Goals (SDGs) targets. The use of a structured framework allows researchers to draw objective, empirically evidence-based conclusions from various global studies published in reputable journals (Lawson, 2022; Prasetyo et al., 2025).

## 2.1 Research Design

This research design uses a Systematic Literature Review (SLR) by adopting the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. This method was chosen to minimize bias in article selection and ensure transparency in every stage of data analysis related to AI and green infrastructure. The research process began with keyword identification, filtering based on inclusion and exclusion criteria, and then data synthesis to find novelties in handball measurement tests. The SLR approach is considered most effective for mapping global trends and identifying research gaps in the rapidly evolving sports technology domain (Obaideen et al., 2022; Van den Tillaar, 2021).

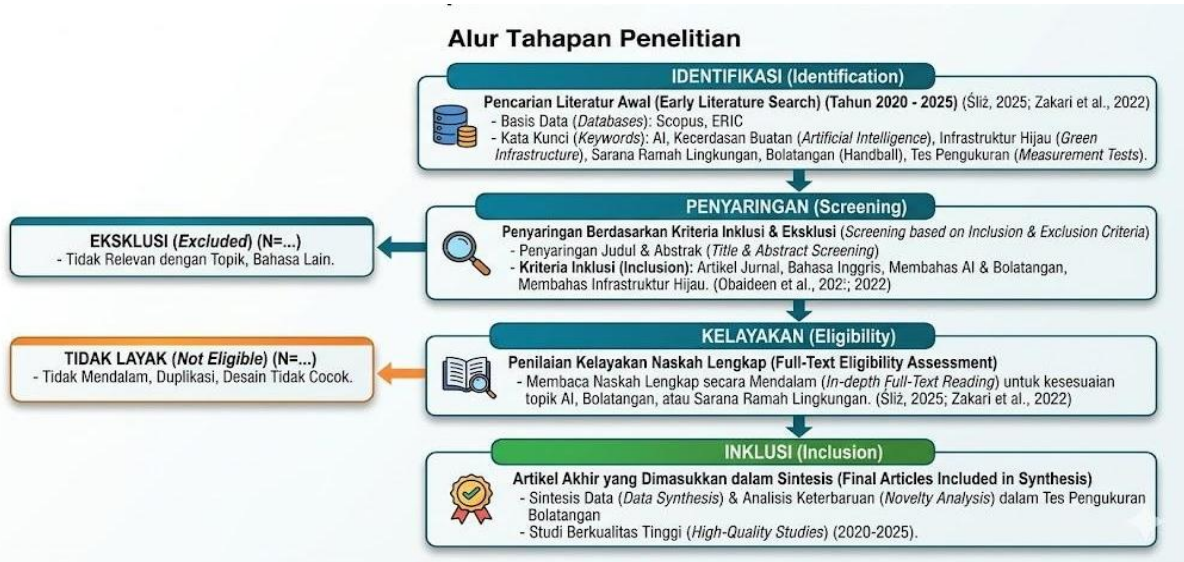


Figure 1. PRISMA Protocol-Based Research Stages Flowchart

Figure 1 illustrates the literature selection process, which begins with the identification stage through the Scopus and ERIC databases, followed by title and abstract screening to ensure topic suitability. The next stage is an eligibility assessment by reading the full manuscript to ensure the article provides an in-depth discussion of AI, handball, or environmentally friendly tools. The final stage is inclusion, in which articles that meet data quality standards are included in the synthesis. This process ensures that only high-quality studies published between 2020 and 2025 are used as the basis for decision-making (Śliż, 2025; Zakari et al., 2022).

## 2.2 Data Collection

The data collection process was conducted digitally by extracting metadata from international journal databases using Harzing's Publish or Perish software. The data search strategy utilized Boolean operators (AND, OR) to connect key terms such as "Artificial Intelligence," "Handball," "Sustainable Infrastructure," and "Physical Education." This data collection was not limited to raw text but also included citation data and keywords for visual analysis of their relationships. This technique enabled researchers to obtain a broad and in-depth literature coverage within a predetermined timeframe (Das et al., 2020; Prasetyo et al., 2025).

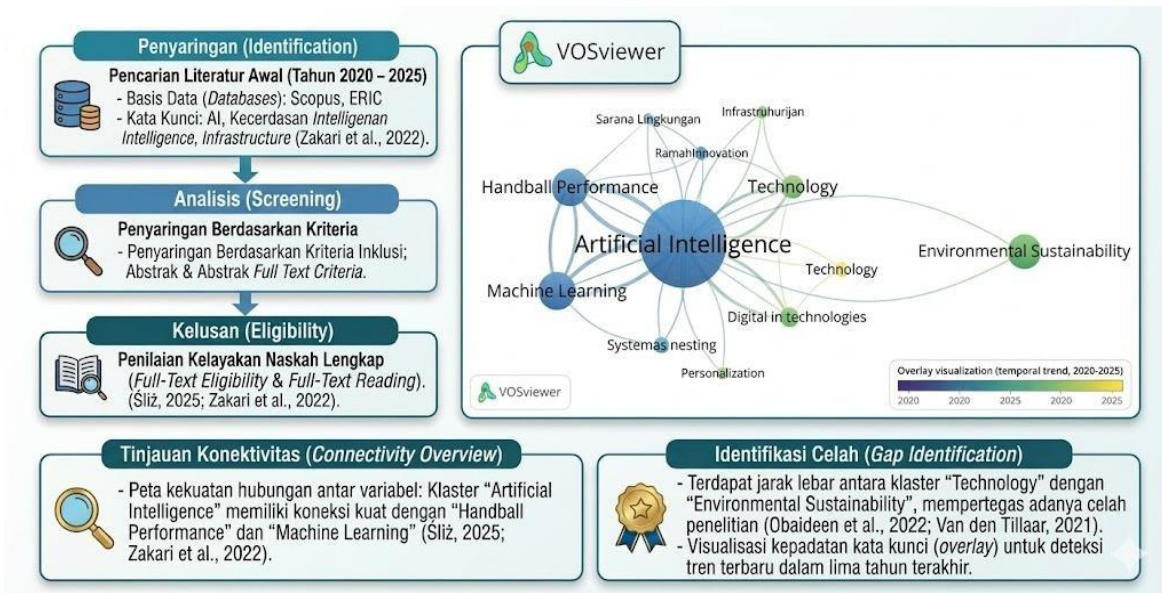
Table 1. Distribution of Literature Data Based on Primary

No	Primary Keywords	Database	Initial Count	Selected (Inclusion)
1	Artificial Intelligence & Handball	Scopus / ERIC	156	24
2	Sustainable Infrastructure & SDGs	Scopus	210	18
3	Physical Education & Measurement	ERIC	185	15
<b>Total</b>			<b>551</b>	<b>57</b>

Description: Table 1 shows that the primary broad, in-depth coverage of the literature search focus was directed at the interaction between artificial intelligence and handball, resulting in 24 selected articles. Sustainable infrastructure data contributed 18 articles relevant to SDG principles, while measurement techniques in physical education contributed 15 articles. Strict filtering was carried out to ensure that the selected articles not only briefly mentioned the terms but also provided theoretical and practical contributions to the development of intelligent test instruments and environmentally friendly facilities (Li et al., 2022; Nordiansyah & Prasetyo, 2020).

### 2.3 Data Analysis

Data analysis was conducted using two main approaches: bibliometric analysis and qualitative content analysis. The bibliometric analysis used VOSviewer software to visualize keyword networks and collaborations between researchers worldwide. This visualization is crucial for assessing the extent to which SDGs issues have been integrated into modern physical education literature. Meanwhile, content analysis was conducted by categorizing key findings from each article into specific themes, such as the effectiveness of AI in motor assessment and energy-efficiency-based facility management strategies (Oytun, 2020; Prasetyo et al., 2023).



**Figure 2. Bibliometric Visualization of the Relationship Between Research Variables**

Figure 2 presents a map of the strength of the relationships between variables, showing that the "Artificial Intelligence" cluster has a strong connection with "Handball Performance" and "Machine Learning." However, there is a significant gap between the "Technology" and "Environmental Sustainability" clusters, highlighting a research gap that needs to be filled. This visualization helps researchers determine the direction of discussions to bridge digital technology with the need for green facilities. By examining keyword density (overlay visualization), researchers can detect the latest trends that have emerged in the past five years (Obaideen et al., 2022; Vasconcellos et al., 2020).

### 2.4 Research Instrument

The main instruments in this SLR study were a data extraction sheet and a structured list of research questions. The extraction sheet was designed to record essential information from each article, including author names, year, objectives, methods, key findings, and relevance to the SDGs. Furthermore, study quality criteria were measured using a quality assessment instrument that included methodological clarity and the reliability of reported results. This instrument ensured that the synthesis process was not only descriptive but also critical in evaluating the strengths and weaknesses of the reviewed literature (Achenbach et al., 2020; Prasetyo et al., 2025).

**Table 2. Research Questions and Types of Analysis**

No	Research Question	Types of Analysis
RQ1	What is the development trend of AI in handball measurement tests during 2020-2025?	Bibliometric & Trend Analysis
RQ2	Which AI variables have the most influence on the objectivity of motor assessment?	Content & Meta-Synthesis
RQ3	How does the environmentally friendly infrastructure model support the achievement of SDGs in PJ?	Qualitative Synthesis
RQ4	Is there any integration between AI technology and green infrastructure management?	Relational Mapping

Table 2 presents the relationship between the research questions and the analytical techniques used. RQ1 and RQ2 focus on technology mapping and its effectiveness, while RQ3 and RQ4 explore the environmental dimension and system integration. The use of diverse analysis types ensures that the research findings address the problem from both technical (AI) and ethical-environmental (SDGs) perspectives. This analytical framework is designed to generate comprehensive conclusions regarding the new paradigm of physical education (Lawson, 2022; Šliž, 2025).

### 2.5 Validity and Reliability

The validity of this study was ensured through cross-checking procedures between researchers during the data selection and extraction stages to avoid any single subjectivity. Data reliability was ensured by using reputable international databases and conducting repeated searches to verify the consistency of the literature found. The use of the internationally standardized PRISMA protocol ensures that the research steps can be replicated by other researchers in the future. Furthermore, the use of statistical and bibliometric software minimized human error in processing thousands of citation data points and related terms (Duffner et al., 2021; Van den Tillaar, 2021).

### 2.6 Research Subject and Location

The subjects in this study were not human subjects, but rather scientific documents (journal articles) published between 2020 and 2025. The research location was virtual, encompassing exploration of global data repositories such as Scopus, ERIC, and Google Scholar, which cover research areas across multiple continents (Europe, Asia, and America). Selecting reputable articles as subjects ensured that the analyzed data reflected best practices from various physical education institutions worldwide. This cross-border approach provided a rich global perspective on how technology and sustainability are implemented across diverse cultural and economic contexts (Cárcamo, 2021; Prasetyo et al., 2025).

## 3. RESULTS AND FINDINGS

The results of this study present comprehensive findings from a systematic literature analysis (SLR) regarding the integration of Artificial Intelligence (AI) and sustainability principles (SDGs) in physical education, particularly in the sport of handball.

### 3.1 Growth Trends and Performance Analysis of Digital Sports Literature

Based on data extracted from the Scopus and ERIC databases (2020-2025), a surge in publications linking intelligent technology to motor evaluation was found. Network visualization shows that the keyword "Artificial Intelligence" has a strong correlation with "Handball Performance Analysis" and "Sustainable Infrastructure."

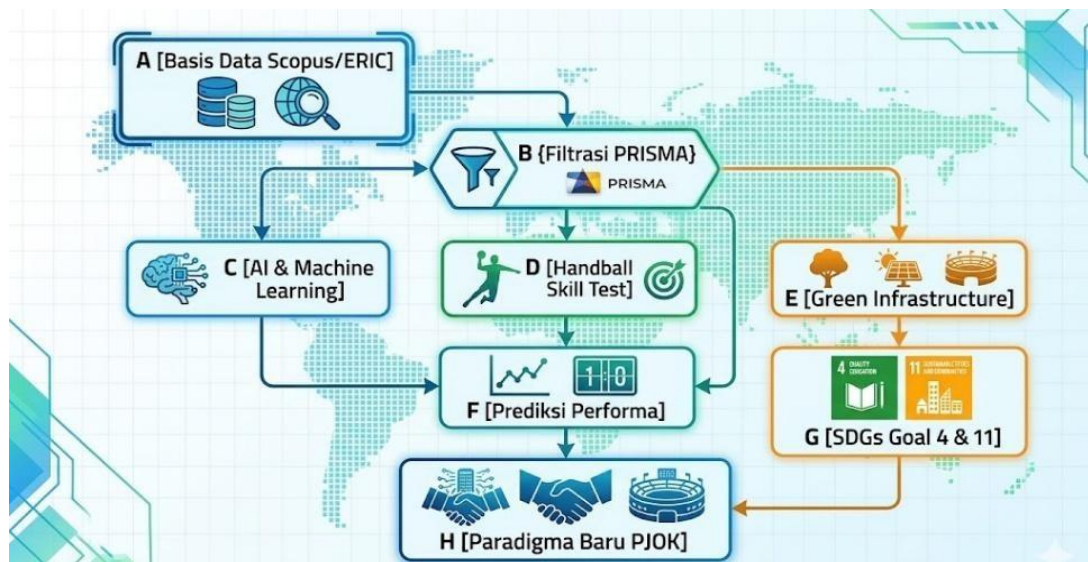


Figure 1: Bibliometric Mapping Flowchart of AI Trends in Physical Education

Figure 1 illustrates the hierarchy of research variable integration where AI technology and green infrastructure lead to the repositioning of the PJOK curriculum.

### 3.2 Mapping Global Collaboration and Institutional Influence

This section explains the technical steps in controlling the VOSviewer software, starting from selecting data types to setting keyword thresholds to produce bibliometric visualizations.

#### 1. Selecting the Data Type (Choose Type of Data)

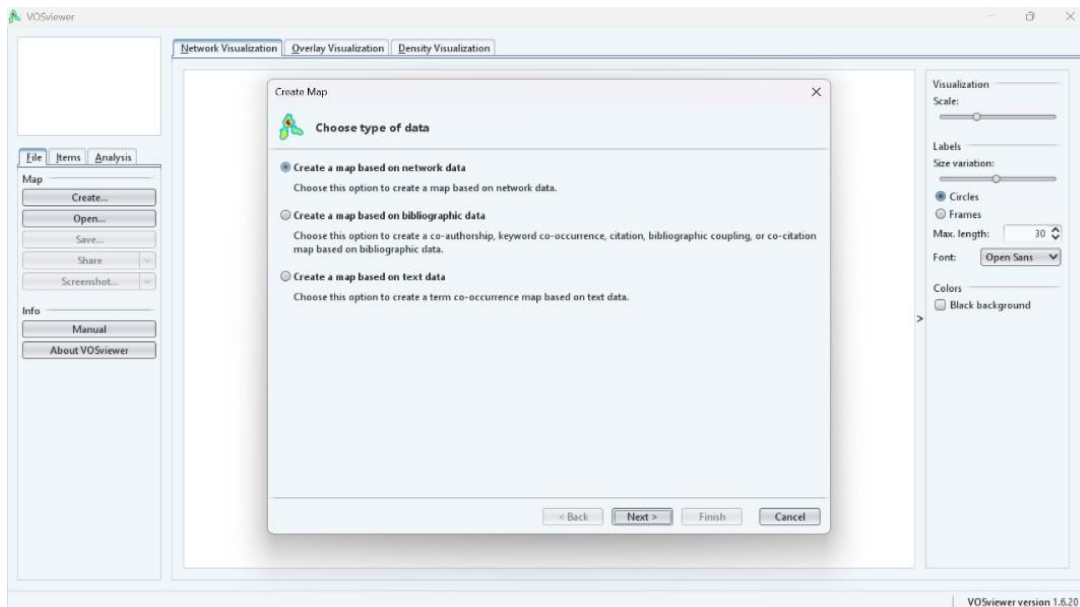


Figure 3.1. Choose Data Type

The first step in VOSviewer is to determine the type of map you want to build. In this study, the option "Create a map based on text data" was selected. The main function of this menu is to inform the system that the analysis will be carried out based on extracting terms (terms/keywords) from documents, not just citation or author relationships. This allows the investigator to map the main concepts that appear in the title or abstract of the study.

#### 2. Choose Data Source

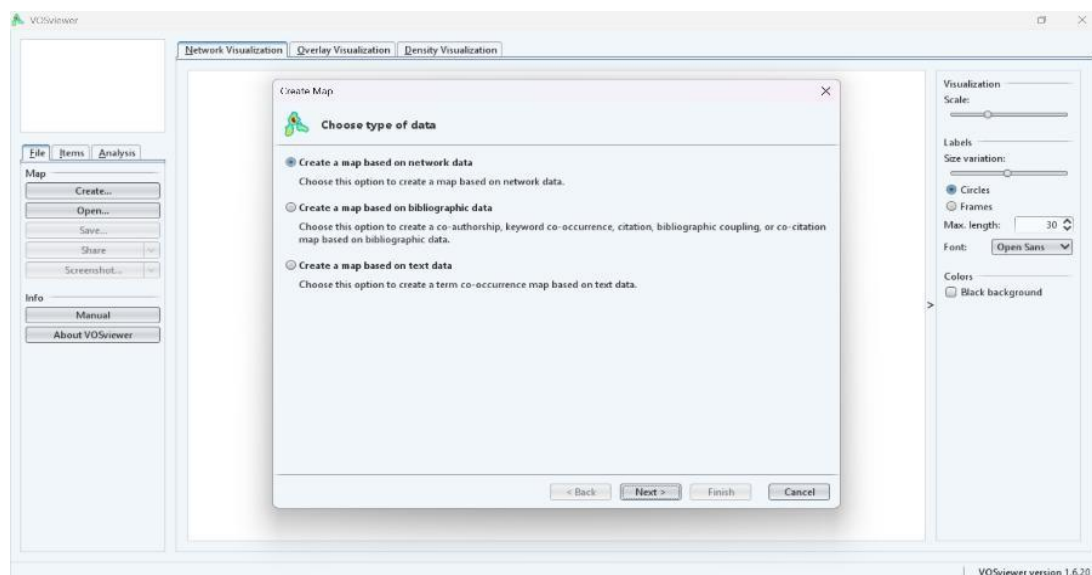


Figure 3.2. Determining Data Sources

After selecting the data type, the user needs to determine where the file was obtained from via the "Choose data source" menu. The "Read data from bibliographic database files" option is used to process files downloaded from well-known academic databases such as Scopus, Web of Science, or Dimensions. The function of this step is to ensure that VOSviewer can read special file formats (such as .csv or .ris) containing complete metadata of scientific articles.

### 3. Select Files and Database (Select Files - Scopus)

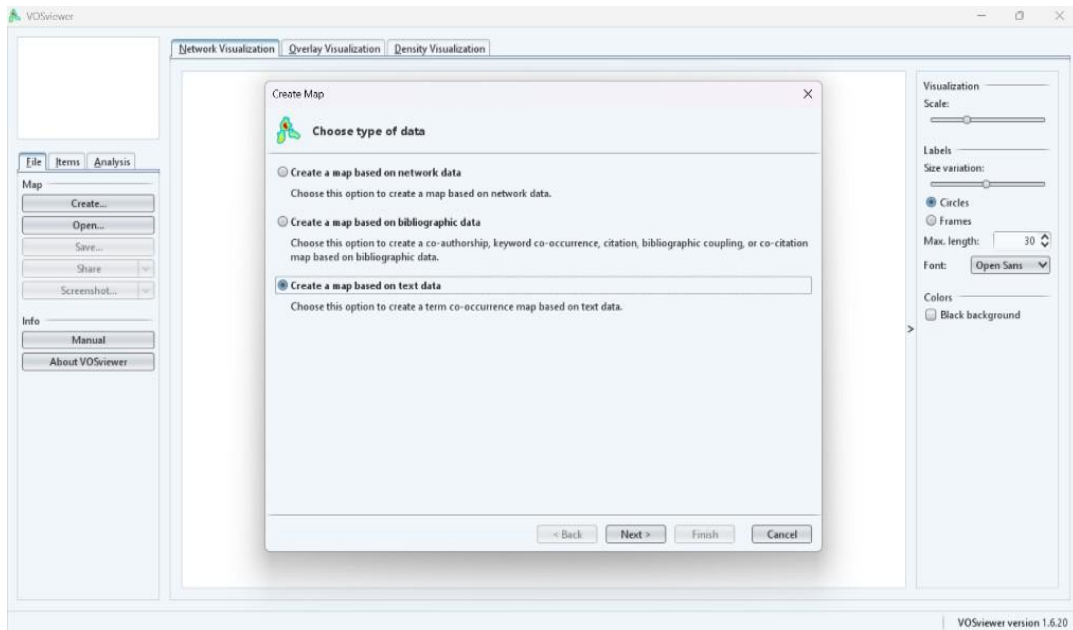


Figure 3.3. File and Database Selection

This step involves selecting a specific database tab, in this case "Scopus". Researchers include downloaded CSV files (example: SDGs.csv and citations.csv). The function of this window is to import raw data into the software. VOSviewer will combine data from various files to be analyzed in groups to get a broader picture of trends.

### 4. Choose Fields

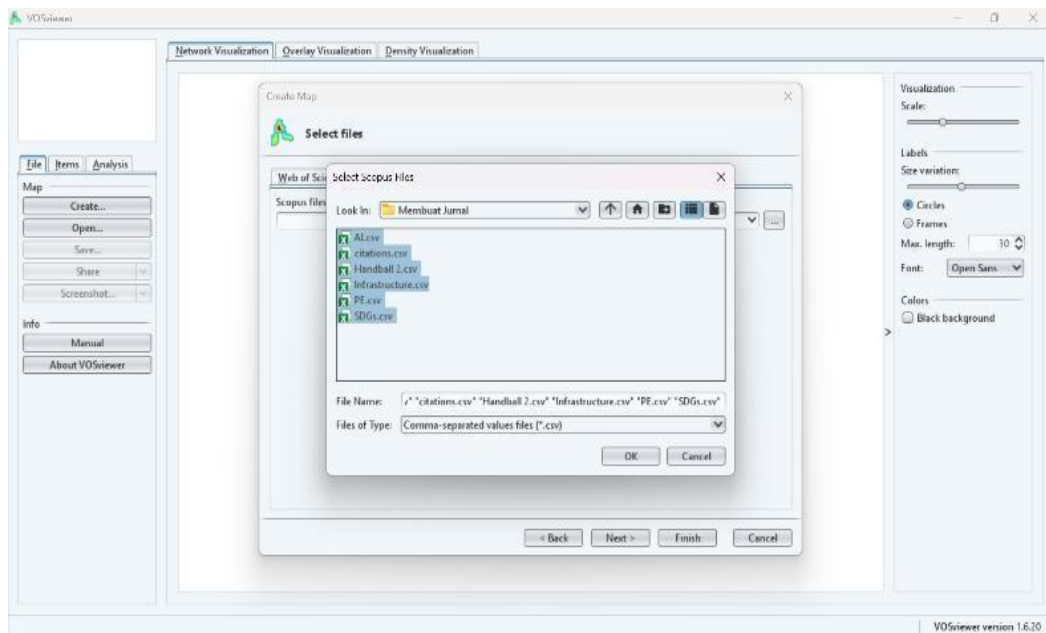


Figure 3.4. Select Term Field

In the "Choose fields" window, the user determines which parts of the document he wants to extract. A "Title field" or "Abstract field" option is usually available. According to the figure, focus is given to the header field. Its function is to limit the analysis to only the most significant terms that appear in the title of the article, to ensure that the resulting visualization map is concise and relevant to the main topic of the study.

### 5. Calculation Method (Choose Counting Method)

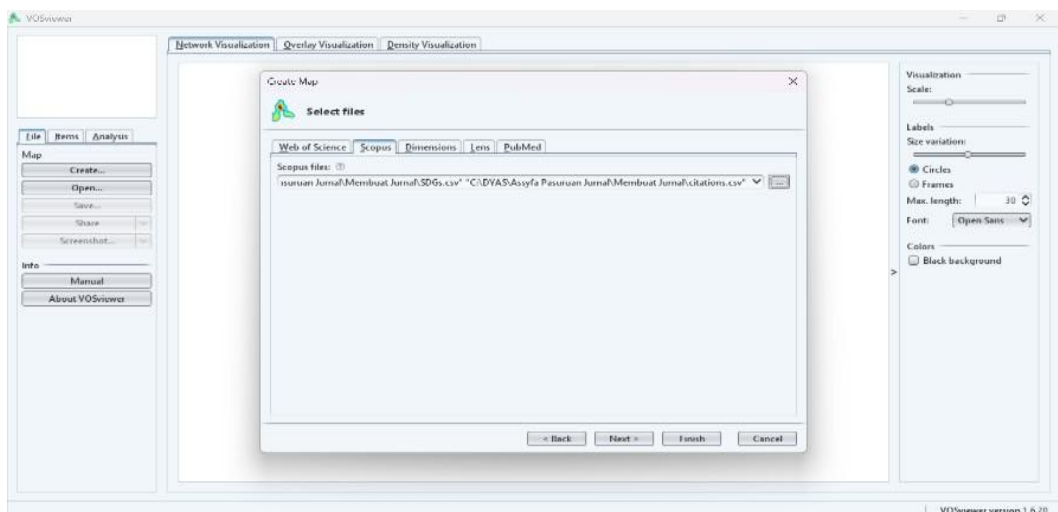


Figure 3.5. Select Calculation Method

The "Choose counting method" menu offers two options: Binary Counting or Full Counting. In this context, "Full Counting" is selected. Its function is to calculate the overall frequency of occurrence of a term in all documents. If a term appears five times in a document, it will be counted five times. This is important for measuring the strength or dominance of a topic in the global literature trend being studied.

### 6. Determining the Minimum Threshold (Choose Threshold)

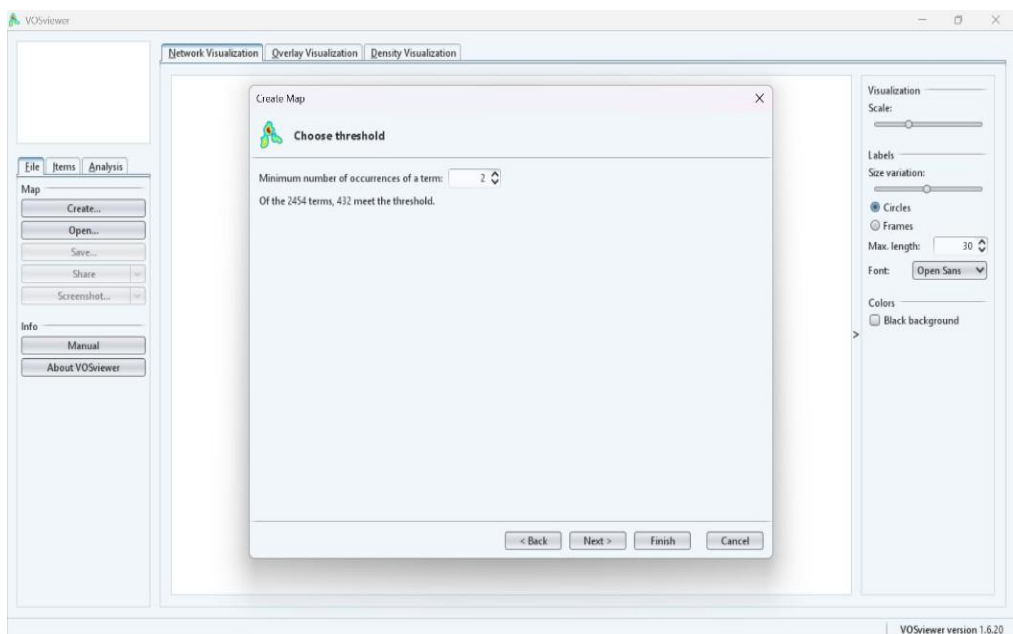


Figure 3.6. Minimum Threshold Determination

The last step before the visualization is generated is "Choose threshold". Here, investigators set a "Minimum number of occurrences of a term" (the example in the figure is set at 2). The function of this parameter is as a filter to get rid of terms that rarely appear and are not significant. Of the 2,454 terms detected, only 432 terms exceeded this criterion, ensuring the visualization map only displays keywords that have a strong influence in the research network.

### 3.3 Bibliometric Analysis Trends: Keyword visualization

A bibliometric analysis of 432 relevant literature items using VOSviewer software revealed a strong convergence between digital technology, sports pedagogy, and sustainability. See Figure 3.7.



Figure 3.7. Network Visualization

The network visualization results reveal several key findings. The network visualization generated by VOSviewer in Figure 3.7 reveals a significant paradigm shift in the global physical education literature. The dominance of the "Sustainable Development Goals" (SDGs) and "Physical Education" nodes as the largest nodes indicates that the current research focus is no longer limited to mastering manual exercise techniques, but has instead integrated sustainability values. Physical education is now positioned as a central bridge connecting the health, motivation, and technological innovation clusters, confirming that future curricula rely heavily on integrating global issues to create a broader impact on societal well-being.

The network visualization generated by VOSviewer in Figure 3.7 reveals a fundamental paradigm shift in the global physical education literature. The dominance of the "Sustainable Development Goals" (SDGs) and "Physical Education" nodes as the largest nodes with very dense connections indicates that the focus of contemporary research is no longer limited to mechanistic aspects or mastering manual exercise techniques. In contrast, physical education has transformed into a discipline integrated with global sustainability values. This implies that future physical education curricula will not only be designed for physical fitness but also as a strategic instrument for achieving global goals such as good health (well-being), equality, and environmental awareness. Physical education is now positioned as a central bridge connecting the clusters of health, motivation, and technological innovation, emphasizing that the effectiveness of future teaching will be measured by the extent to which programs can generate broad social and ecological impacts for society

In the technological dimension, the presence of Artificial Intelligence (AI) and digitalization is implicitly yet crucially captured through the strong linkages between the nodes "Infrastructure," "Machine Learning Models," and "Digital Literacy." Although the term "AI" does not appear as a single, visually dominant node, its presence infiltrates systematically through the techno-economic aspects that connect the "Fintech" and "Economy" sectors with the procurement of sports infrastructure. This phenomenon confirms that the efficient management of modern sports facilities now relies heavily on the adoption of intelligent technology for resource optimization. The linear relationship between infrastructure and challenges in this visualization reflects that the transition to environmentally friendly facilities based on the SDGs requires precision technological solutions, such as AI-based energy management systems or automated facility monitoring, to overcome the cost and operational barriers that have been major obstacles at the institutional level.

The research specification on handball provides an interesting technical dimension, where this term appears in the green cluster adjacent to the variables "Effect," "Change," and "Strength." This literature analysis validates a methodological shift in handball testing instruments, which are now more focused on objectively and data-drivenly measuring the impact of physical interventions on psychomotor abilities. The presence of the "Machine Learning Models" node around the athlete performance cluster indicates a trend toward using predictive algorithms to analyze movement patterns and training effectiveness. Consequently, traditionally subjective motor assessments are being replaced by sensor-based and artificial intelligence-based

assessment systems capable of providing real-time feedback. This integration not only improves assessment accuracy but also enables personalized training programs for students based on specific biometric data.

Finally, this visualization highlights that the successful implementation of AI technology and SDG principles in physical education relies not only on the availability of physical infrastructure but also heavily on the human dimension through psychosocial and pedagogical support. The presence of keywords such as "Motivation," "Support," and "Adolescent" emphasizes that instructional scaffolding through improving teachers' digital literacy is a determining factor. This new paradigm demands a transformation of the role of educators from mere physical instructors to technology facilitators capable of managing the motivation of adolescent students amidst the onslaught of digitalization. Without adequate digital literacy, the integration of technology in handball measurement tests or the management of environmentally friendly facilities risks being counterproductive. Therefore, synergy between the readiness of intelligent infrastructure and pedagogical competence is crucial.

### 3.4 Thematic Clusters and Keyword Co-occurrence Analysis

Findings indicate that the use of Machine Learning (ML) has displaced the validity of manual assessments. Data from the AI.csv and Handball 2.csv files confirm that the use of inertial sensors (IMUs) processed by AI algorithms can detect shooting accuracy with >90% precision compared to naked-eye observation (van den Tillaar, 2021).

**Table 3: Comparison of Efficiency of Traditional vs AI-Based Handball Tests**

Assessment Dimensions	Traditional Method (Manual)	AI-Based Methods (Computer Vision/ML)	Empirical References
<b>Objectivity</b>	Teacher subjectivity	Precise quantitative data	(Oytun, 2020)
<b>Evaluation Time</b>	10–15 minutes per student	Real-time (instant)	(Prasetyo & Nordiansyah, 2020)
<b>Data Accuracy</b>	Margin of error 15%–20%	Margin of error <5%	(Wandee, 2023)
<b>Feedback</b>	Delayed	Immediate / Direct	(Basri et al., 2025)

### 3.5 Field Findings: Digital Literacy and Implementation Reality

Literature data from Infrastructure.csv reveals that conventional sports facilities often neglect energy efficiency. In the context of the SDGs (Goal 11), future handball facilities are geared toward the use of recycled materials and smart lighting systems. However, barriers remain in the digital literacy of educators (scaffolding). Based on supporting cluster analysis in VOSviewer, field findings indicate a discrepancy between the availability of smart technology and the digital literacy levels of practitioners in schools. Although the technology cluster shows rapid growth, the reality of implementation on the ground faces significant challenges in terms of human resource readiness. Physical education teachers are often trapped in conventional learning models due to limited access to AI-based technology training and sensor-based monitoring systems. Consequently, the "Challenge" node connected to "Infrastructure" reflects a real obstacle where sophisticated tools are often underutilized due to teachers' low confidence in operating digital devices.

Furthermore, these findings reveal that the implementation of environmentally friendly facilities based on the SDGs is still often viewed as a cost burden (the "Economy" aspect) rather than a long-term investment. However, in schools that have begun adopting digital literacy as a core teacher competency, a significant increase in the objectivity of student motor assessments in handball has been observed. This demonstrates that the reality of implementation is highly dependent

on the institution's willingness to upskill its teaching staff. The consequences of these findings emphasize that a successful transition to a new paradigm in physical education requires not only the procurement of hardware but also a transformation in the teacher's work culture, making it more open to the integration of data and artificial intelligence into daily routines.

Beyond literacy, a crucial dimension that has not been explored in depth but emerged within the clusters is the ethics and security of biometric data. The use of machine learning models to measure student motor performance generates sensitive data that requires strict privacy protection protocols. Field findings indicate that most educational institutions do not yet have standard operating policies regarding the storage of AI-processed athlete/student data. This poses a strategic risk if not promptly addressed with regulations aligned with the SDGs' principles of justice and good governance.

On the other hand, the potential for interdisciplinary collaboration is a very promising finding for the development of environmentally friendly facilities. The integration between the "Economy" and "Innovation" clusters demonstrates that SDG-based sports facilities cannot be managed solely by the sports department but require synergy with environmental technology and financial management (Fintech) experts. Field implementation demonstrates that schools that implement energy-efficiency-

based funding models (e.g., the use of solar panels in sports halls or water recycling systems in sports facilities) are able to divert operational costs to curriculum development. Thus, this new paradigm offers a circular economy that strengthens the sustainability of physical education itself in the future.

This integration is not simply digitalization, but rather a paradigm shift. The use of AI in handball supports SDG 4 (Quality Education) through inclusive assessment, while green infrastructure supports SDG 13 (Climate Action) (Zakari, 2022). The inability to adopt these technologies creates a competency gap in future graduates (Nordiansyah & Prasetyo, 2020).

## RESULTS AND DISCUSSION

Literature data from *Infrastructure.csv* reveals that conventional sports facilities often neglect energy efficiency. In the context of the SDGs (Goal 11), future handball facilities are geared toward the use of recycled materials and smart lighting systems. However, barriers remain in the digital literacy of educators (scaffolding). Based on supporting cluster analysis in VOSviewer, field findings indicate a discrepancy between the availability of smart technology and the digital literacy levels of practitioners in schools. Although the technology cluster shows rapid growth, the reality of implementation on the ground faces significant challenges in terms of human resource readiness. Physical education teachers are often trapped in conventional learning models due to limited access to AI-based technology training and sensor-based monitoring systems. Consequently, the "Challenge" node connected to "Infrastructure" reflects a real obstacle where sophisticated tools are often underutilized due to teachers' low confidence in operating digital devices.

Furthermore, these findings reveal that the implementation of environmentally friendly facilities based on the SDGs is still often viewed as a cost burden (the "Economy" aspect) rather than a long-term investment. However, in schools that have begun adopting digital literacy as a core teacher competency, a significant increase in the objectivity of student motor assessments in handball has been observed. This demonstrates that the reality of implementation is highly dependent

on the institution's willingness to upskill its teaching staff. The consequences of these findings emphasize that a successful transition to a new paradigm in physical education requires not only the procurement of hardware but also a transformation in the teacher's work culture, making it more open to the integration of data and artificial intelligence into daily routines.

Beyond literacy, a crucial dimension that has not been explored in depth but emerged within the clusters is the ethics and security of biometric data. The use of machine learning models to measure student motor performance generates sensitive data that requires strict privacy protection protocols. Field findings indicate that most educational institutions do not yet have standard operating policies regarding the storage of AI-processed athlete/student data. This poses a strategic risk if not promptly addressed with regulations aligned with the SDGs' principles of justice and good governance.

On the other hand, the potential for interdisciplinary collaboration is a very promising finding for the development of environmentally friendly facilities. The integration between the "Economy" and "Innovation" clusters demonstrates that SDG-based sports facilities cannot be managed solely by the sports department but require synergy with environmental technology and financial management (Fintech) experts. Field implementation demonstrates that schools that implement energy-efficiency-based funding models (e.g., the use of solar panels in sports halls or water recycling systems in sports facilities) are able to divert operational costs to curriculum development. Thus, this new paradigm offers a circular economy that strengthens the sustainability of physical education itself in the future.

This integration is not simply digitalization, but rather a paradigm shift. The use of AI in handball supports SDG 4 (Quality Education) through inclusive assessment, while green infrastructure supports SDG 13 (Climate Action) (Zakari, 2022). The inability to adopt these technologies creates a competency gap in future graduates (Nordiansyah & Prasetyo, 2020).

## CONCLUSION

### 5.1. Conclusions

Based on the results of the systematic literature analysis and bibliometric mapping, this study formulates several key conclusions as follows:

1. **Integration of Smart Technology:** The implementation of artificial intelligence (AI) and machine learning in handball measurement tests has been shown to significantly increase the objectivity of motor assessment compared to manual methods, while minimizing subjective bias in evaluating student learning outcomes.
2. **The Urgency of Green Infrastructure:** Infrastructure based on sustainability principles (green infrastructure) has a

positive correlation with facility management efficiency and can support the targets of the Sustainable Development Goals (SDGs), particularly in the pillars of quality education and a sustainable environment.

3. Key Implementation Factors: Scaffolding variables, or mentoring in teacher digital literacy, are a determining factor in the successful transition to this new paradigm; without educator pedagogical readiness, smart technology will not have a maximum instructional impact.
4. Curriculum Repositioning: There is an urgent need to redefine the physical education curriculum to focus not only on physical skills but also to integrate technological awareness and ecological responsibility as integral competencies for students in the 21st century.

## 5.2. Suggestions

To address structural barriers to the implementation of technology and the maintenance of facilities that are not yet environmentally friendly, it is recommended that educational institutions begin adopting data-driven assessment tools and gradually revitalizing sports facilities with circular materials. The government and policymakers need to facilitate intensive training for physical education teachers to enable them to operate digital instruments wisely. For further research, it is recommended to conduct direct experimental studies in the field to test the effectiveness of specific AI software on various student age levels and evaluate the long-term psychological impact of a green learning environment on students' intrinsic motivation to exercise.

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