

Research Article

Development and evaluation of an IoT-based data analytics system for optimizing football learning in higher education

M. Said Zainuddin^{1*}, Sudirman², Ahmad Zakaria³^{1,2,3} Faculty of Sport Science, Universitas Negeri Makassar, Jl. Wijaya Kusuma Raya No. 14, Makassar, South Sulawesi Province, 90222, Indonesia*Corresponding author, email: saidzainuddin@unm.ac.id**ABSTRACT**

Background: While smart technology and big data have advanced, football instruction at Indonesian universities lags. Most local classrooms lack high-tech tools, presenting an opportunity to modernize sports science. Objective: This research aimed to develop an IoT-based system and analytics platform for higher education, equipping students and coaches with data-driven insights for modern football training. Methods: Conducted at Universitas Negeri Makassar over five months (August–December), the study followed a Research and Development approach with six phases: needs analysis, design, development, expert validation, field trials, and effectiveness evaluation. Participants included Physical Education students divided into experimental (IoT system) and control (traditional methods) groups. Instruments concisely combined wearable sensors (accelerometers, gyroscopes, GPS) for movement tracking with skill assessments, expert questionnaires, and interviews. Quantitative data were analyzed via paired and independent-samples t-tests; effect sizes via partial eta-squared (η^2p); reliability via intraclass correlation coefficients (ICC). Qualitative data were reduced, displayed, and summarized. Result: Key outcomes included a validated four-layer IoT system (expert-approved in field, technology, and pedagogy), a data analytics model spanning planning, realization, control, and evaluation, and significant skill improvements (passing accuracy, sprint speed, agility, kicking power) in the experimental group with large practical effects. Conclusion: The IoT system proved feasible and effective for enhancing football skills. Future research could scale it to broader athletic training contexts or integrate AI for real-time feedback.

ARTICLE HISTORY

Received January 29, 2026

Accepted March 29, 2026

Published April 01, 2026

KEYWORDS

Data analytics; football learning; Internet of Things; sports education; university.

Introduction

The rise of information and communication technology in the twenty-first century has reshaped countless dimensions of human life, and education ranks among the most visibly affected. The Fourth Industrial Revolution, defined by the fusion of digital technology, automation, and real-time data exchange, has pushed educational stakeholders at every level to move away from conventional instruction and toward more integrative, technology-driven approaches (Ait Ouchtout et al., 2025). The Internet of Things (IoT) is a key part of this change, comprising a network of connected physical devices that automatically collect and share data over the internet, removing the need for direct human involvement (Al-Atawi et al., 2023). The integration of IoT within educational contexts facilitates the creation of learning environments that are more intelligent, adaptable, and genuinely tailored to the specific requirements of individual students (Bruno & Canina, 2019). Furthermore, the integration of IoT with big data and artificial intelligence has, on a larger scale, given rise to the concept of the smart university. In this institution, learning processes can be managed with significantly greater efficiency and informed by empirical data. This digital shift touches not only how subject matter is delivered in

classrooms but also how physical activities, including sports training, can be tracked, analyzed, and systematically refined. To prepare graduates for the digital age, universities must adopt advanced technologies; therefore, studying how to use IoT infrastructure in university teaching has become an essential area of research (Orellana, 2025). The Internet of Things (IoT), a key technology in modern education, offers considerable potential in various fields, including physical education and sports.

Recent findings indicated that embedding IoT into educational software yields concrete benefits, including greater operational efficiency, improved infrastructure management, and stronger data security (Gowda, Sortur, & Mishra, 2025; Mohamad et al., 2024). Monitoring systems leveraging IoT and big data analytics can significantly enhance the ability to leverage technology for real-time health and infrastructure surveillance, a methodology directly applicable to monitoring student performance in football training (Saha, 2025). These observations dispel lingering doubts regarding the practical utility of IoT, as it has already yielded quantifiable outcomes within the educational sphere and related domains. Some frameworks have integrated character development into IoT-based learning in Physical Education, Health, and Recreation (PJOK), further underscoring the technology's relevance to sports education. Leveraging IoT in the Society 5.0 learning landscape is an effective way to close the gap between contemporary learning demands and what traditional teaching methods can realistically deliver (Nasih & Mansur, 2024). This point is reinforced by gains in students' technological competencies and Industry 4.0 skills through computer vision and IoT training programs (Romeral et al., 2021). Taken together, these converging findings lay a solid scientific foundation for deeper inquiry into how IoT infrastructure can be optimally deployed to support football learning at the university level. Alongside the rise of IoT and analytics, the way data is managed and applied within educational processes has shifted considerably.

Big data applications have spread across major strategic industries, including education, where large-scale analysis supports more accurate, evidence-driven decision-making (Mohite et al., 2025). In practice, this takes the form of learning analytics tools that map student learning patterns, pinpoint weaknesses, and produce targeted instructional recommendations. These capabilities matter especially in physical education and football, where students' motor performance and technical skills can be objectively captured through IoT-connected sensors integrated with analytics platforms. The use of artificial intelligence in educational research has unlocked analytical capabilities previously out of reach with manual methods, enabling the tailoring of content and teaching strategies to individual students' specific needs (Darayseh, 2025). This is particularly relevant in university football, given the significant variation in initial skill levels, physical conditioning, and motor learning among student-athletes; consequently, personalized instruction has evolved from a supplementary measure to a fundamental necessity. AI-driven personalization in higher education is viewed as a transformative development, albeit one that requires meticulous preparation and sufficient infrastructure to realize its full potential.

The pandemic's arrival in 2020 spurred a swift digital transformation in Indonesian education, forcing universities to embrace digital technologies more widely. This shift catalyzed broader digitalization, even as institutions grappled with significant obstacles around infrastructure readiness and human resource capacity. The enduring lesson from that period is that robust digital infrastructure is a fundamental prerequisite for keeping educational processes running under any conditions, and that this requires systematic, data-driven planning to use resources efficiently. In the post-pandemic era, the demand for learning systems that are not just online but also intelligent and adaptive has become more pressing, particularly for practice-intensive courses like football, where physical presence and direct interaction remain essential yet can be meaningfully enriched by technology (Yao, 2026). Rapid advances in web-based adaptive e-learning systems support the justification for applying similar approaches in the domain of sports education, helping educators design lessons that are more structured and data-driven (Rishard et al., 2022). Conversely, integrating IoT infrastructure and data

analytics introduces substantial obstacles, including cybersecurity risks within IoT ecosystems. The proliferation of device connectivity across campus networks amplifies the risk of security vulnerabilities, underscoring the importance of machine learning-based intrusion detection and Zero Trust architectures as essential protective strategies (Gamilla et al., 2024).

The stakes are particularly high when wearable sensors gather sensitive personal information from student-athletes, including heart rate and movement patterns. Furthermore, the digital infrastructure on campuses varies significantly, creating major obstacles to consistent IoT implementation (Hammouri et al., 2026). Building technological literacy across the entire academic community is an indispensable first step before intelligent systems can be fully operationalized (Jeffryes, 2025). These challenges dictate that IoT and data analytics systems for university football learning must be designed with flexibility and contextual sensitivity, shaped by infrastructural realities and learning needs. Based on this analysis, a clear gap appears between the potential of IoT and data analytics and their actual use in sports education in Indonesian universities. While some IoT-based frameworks for physical education exist, they remain largely theoretical and have not been tested in specific sports, such as football, using measurable performance indicators (Awouda et al., 2024). There is a pressing need for research on adaptive system designs that fit the unique context of Indonesian higher education, moving beyond science education to examine underrepresented fields like sports.

Furthermore, while learning analytics have proven effective in primary schools, their application in complex, hands-on university sports courses remains underexplored. Cybersecurity measures have also not yet been integrated into campus-based IoT sports systems, and big data remains primarily administrative rather than focused on active learning phases. Most importantly, no study has combined all four phases of sports training, planning, realization, control, and evaluation into a single framework using IoT in an Indonesian university setting. This article addresses these gaps by examining how IoT infrastructure and data analytics can optimize football learning through a validated architectural design and an empirical evaluation of system effectiveness (Gulyamov, 2024). The research problem centers on the lack of objective, real-time feedback in traditional university football instruction, and it is hypothesized that an integrated IoT system will significantly improve students' technical performance indicators. The purpose of this writing is to demonstrate the feasibility and impact of a four-layer IoT system on football skill acquisition in higher education.

The literature review above points out several research gaps that support this article's originality. First, while Maulana et al. (2024) developed an IoT-based PJOK learning framework, their work remains theoretical. It has not been tested in a specific sport, like football, using standard performance measures. Second, Suhendry et al. (2025) identified ongoing infrastructure and institutional challenges to the use of AI for personalized learning in higher education, underscoring the need for research on adaptive system designs that fit Indonesia's context. Third, Sangaji et al. (2025) called for more research on artificial intelligence in underserved educational contexts, noting that technology-based football learning in higher education remains understudied. Fourth, although Kristinasari et al. (2026) showed that learning analytics work well in primary schools, their use in hands-on sports courses at the university level, which are more complex, is still underexplored. Fifth, while Simanjuntak & Sijabat (2024) and Darmawan et al. (2025) discussed cybersecurity in IoT networks, these security measures have not yet been included in campus-based IoT sports learning systems. Sixth, Muhamad & Sumiah (2025) found that big data in education is primarily used for administrative tasks rather than for active learning, such as sports training, which generates substantial performance data. Seventh, no study so far has combined all four phases of sports training planning, execution, control, and evaluation into a single framework using IoT and data analytics in an Indonesian university setting. This article aims to address these gaps with a thorough, context-based, and practical approach.

Method

Research Design

This study adopted a Research and Development (R&D) methodology to develop and validate an IoT infrastructure system and a data analytics platform to improve football learning in higher education (Figure 1). Conducted at Universitas Negeri Makassar over five months (August–December), the process unfolded through six iterative phases: needs analysis, architectural design, system development, expert validation, field trials, and effectiveness evaluation, with adjustments made based on emerging insights at each stage. The field trials employed a quasi-experimental design, pitting an experimental group using the IoT system against a control group receiving conventional instruction.

Needs analysis in August assessed campus digital infrastructure, consulted football instructors, and reviewed the existing curriculum. From September to October, the architectural design and development team produced a four-layer IoT system: sensing (wearables such as accelerometers, gyroscopes, and GPS), network, processing, and application layers. Expert validation (October–November) involved three panels of football coaching specialists, media/technology experts, and sports education scholars, who used Likert-scale questionnaires to gauge feasibility against predefined thresholds. Field trials and effectiveness evaluation (November–December) progressed from small-group quasi-experiments to broader implementation.

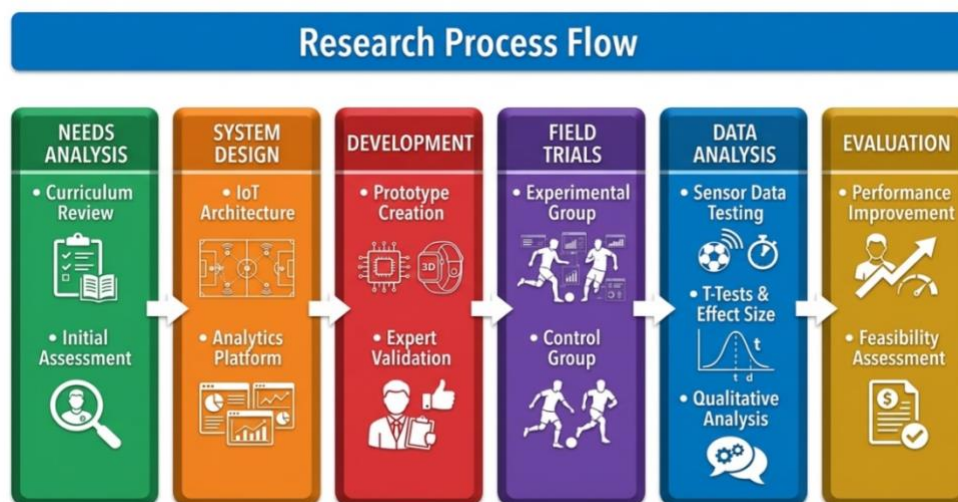


Figure 1. Research Process Flow of IoT-Based Football Learning System Development and Evaluation in Higher Education

Participants

The population consisted of Physical Education, Health, and Recreation students enrolled in the university's football course that semester. Purposive sampling selected 12 participants based on network access, willingness, and baseline equivalence in academics and fitness; they were evenly divided into experimental and control groups. Pre-tests confirmed group homogeneity, and the site provided reliable infrastructure, internet access, and a football field for device deployment. Sample size accounted for significance ($\alpha=0.05$), power (0.80), and anticipated effect sizes; informed consent preceded all activities.

Ethical Approval Statement

Ethical approval for this research was granted by Universitas Negeri Makassar under approval letter number 6205/UN36.3/PP.2025. The study was conducted in accordance with the principles of the Declaration of Helsinki. All participants provided written informed consent prior to their participation in the study.

Research Instruments

Data collection integrated standardized football skill tests (passing accuracy, sprint speed, agility, kicking power), expert questionnaires, structured interviews, and sensor-tracked metrics. Instruments were pre-validated for content and reliability, with intraclass correlation coefficients (ICC) verifying sensor consistency. Technical validation included ICC for sensors and latency checks for data transmission.

Data Analysis

Quantitative analysis applied paired t-tests to examine intra-group pre-test and post-test changes and independent t-tests to compare differences between the experimental and control groups. Expert validation data were analyzed descriptively using feasibility percentages. Qualitative data obtained from interviews and observations were analyzed using Miles and Huberman's framework, including data reduction, data display, and conclusion drawing. Triangulation across multiple data sources was conducted to enhance the credibility and trustworthiness of the findings.

Results and Discussion

Results

Needs Analysis Results

The needs analysis phase yielded several findings that shaped the system design's overall direction. Campus infrastructure assessments revealed that the majority of the universities selected for this initial investigation already have basic Wi-Fi coverage in their academic buildings. However, network access at sports field facilities is significantly restricted, lacking the capacity to support real-time data transmission from sensor devices. This discovery validates the need for organized decision-support systems when developing educational facilities. By implementing these systems, institutions can better manage resource distribution to meet their specific primary objectives.

Interviews with football course lecturers yielded a unified perspective: performance assessment has historically relied on direct visual observation. This method undermines objectivity and renders the simultaneous monitoring of all students nearly impossible. Lecturers emphasized a substantial need for a system capable of automatically recording and analyzing performance data, particularly for technical variables such as passing accuracy, sprint speed, agility, and kicking power, which are difficult to measure consistently through the eye. Curriculum analysis added another layer to this: the football course's learning outcomes span three dimensions: knowledge, technical skills, and attitudes, with the technical skills dimension standing out as the component most in need of technological support for meaningful assessment. The successful implementation of technology requires the concurrent development of infrastructure and human resources; this principle served as a fundamental constraint in designing a system tailored to the practical realities of a campus environment rather than an idealized one. The findings from the needs analysis, when considered collectively, underscore a significant disparity between the demand for data-driven learning assessment and the current technological infrastructure, thereby justifying the development of an Internet of Things (IoT) system that is both practical and feasible within existing constraints.

System Prototype Design and Development

The prototype that was developed is structured around a four-layer architecture, which is intended to comprehensively support all four phases of sports training planning, implementation, control, and evaluation in an integrated manner. The sensing layer employs wearable sensors, namely accelerometers and gyroscopes affixed to students' ankles and waists, in conjunction with GPS modules to monitor positional data and movement dynamics on the field. This arrangement facilitates the continuous acquisition of kinematic and spatial data during each training session. The network layer was structured around a private local Wi-Fi network, with supplementary access points deployed at the sports field to guarantee sufficient signal coverage. An edge computing strategy was implemented,

enabling preliminary sensor data processing on local devices before transmission to the central server; this approach minimizes latency and mitigates network load, aligning with the methodology that highlighted the importance of an efficient network architecture for managing substantial real-time data streams. The processing layer processes sensor-generated performance data to provide analytical feedback and training recommendations. The application layer provides two distinct interfaces: a lecturer-oriented mobile application featuring a real-time monitoring dashboard, historical performance data, and training recommendations; and a student-oriented app that presents individual performance feedback, progress graphs, and personalized training objectives. Data security constitutes a critical element of the system's architecture, integrating sensor transmission encryption and multi-factor authentication for user applications.

By adopting a Zero Trust framework, the design ensures robust data protection and adaptive intrusion monitoring for its IoT components. This structure is further supported by the integration of IoT within the educational software, a move intended to drive organizational efficiency and maximize the utility of existing infrastructure. During the design phase, significant attention was devoted to usability and operational sustainability, thereby ensuring that both lecturers and students could use the system without needing advanced IT skills.

Expert Validation Results

The prototype underwent review by three categories of expert validators, each evaluating distinct aspects within their respective areas of expertise. Football coaching specialists assessed the alignment of the system's performance indicators with established coaching benchmarks, the relevance of algorithm-derived training suggestions to periodization methodologies, and the suitability of feedback content in promoting skill acquisition. Media and IT specialists evaluated the system's overall functionality, interface quality, sensor transmission reliability, and the accuracy and timeliness of algorithmic outputs. Sports education experts scrutinized the alignment with the football course's learning objectives, the pedagogical significance of the data-driven evaluation model, and the system's potential impact on learning quality and student achievements. The primary criterion for this project was ensuring that the IoT infrastructure was built to respect both educational principles and the learners' unique circumstances. This commitment to contextual relevance guided every stage of the system's testing and refinement.

Table 1. Expert Validation Results

Validation Aspect	Validator	Mean Score	Percentage	Category
Alignment with football coaching content	Coaching Expert	4.6	92%	Very Feasible
Relevance of periodization & feedback	Coaching Expert	4.5	90%	Very Feasible
System functionality & usability	IT Expert	4.4	88%	Very Feasible
Transmission reliability & algorithm performance	IT Expert	4.3	86%	Very Feasible
Alignment with learning objectives	Sports Education Expert	4.5	90%	Very Feasible
Pedagogical relevance of data-based evaluation	Sports Education Expert	4.4	88%	Very Feasible
Overall Mean		4.45	89%	Very Feasible

Note: Feasibility criteria: 81–100% = Very Feasible; 61–80% = Feasible; 41–60% = Moderately Feasible; < 40% = Not Feasible.

Evaluation results from all three validator groups were positive, with average scores surpassing the established threshold for feasibility (Table 1). Key improvements involved enhancing the dashboard's usability, integrating a tutorial video, and recalibrating sensor timing to protect student mobility during drills. These refinements ensured the product was sufficiently mature for field testing. By incorporating this feedback, the system was optimized for performance and pedagogical relevance before the trials began.

Field Trial and System Effectiveness Results

The small-group trial surfaced a few minor technical issues, sensor connectivity problems under specific weather conditions, and limited battery life on wearable devices during sessions exceeding 90 minutes. Both were resolved through network configuration adjustments and device power optimization before the large-group trial commenced. In the large-group trial conducted under an experimental design, the experimental group using the IoT system showed significantly greater improvements across all football technical performance indicators compared to the control group receiving conventional instruction. Independent-sample t-tests revealed statistically significant differences between groups on passing accuracy, sprint speed, agility, and kicking power, confirming that the IoT and data analytics system has a positive effect on football learning outcomes (Table 2).

Table 2. T-test comparison between the Post-test results of the Experimental and Control groups

Performance Metric	Experimental Group (Pre-test)	Experimental Group (Post-test)	Control Group (Pre-test)	Control Group (Post-test)	t-test (p-value)
Passing Accuracy (%)	65.4±4.2	75.6±3.1	64.8±4.5	66.1±4.3	<0.001
Sprint Speed (m/s)	6.23±0.35	7.31±0.28	6.25±0.38	6.29±0.36	<0.001
Agility (sec)	15.2±1.1	13.5±0.8	15.3±1.2	15.1±1.1	<0.001
Kicking Power (N)	285±22	316±18	288±25	291±24	<0.001

Note: Data presented as Mean, Standard Deviation. p-values refer to the independent samples t-test comparison between the Post-test results of the Experimental and Control groups.

The implementation highlights how educational technology fosters the engagement necessary for student success. Technical validation showed that sensor reliability reached optimal levels, ensuring the data is a dependable foundation for performance evaluation. Although network congestion occasionally impacted latency, the system maintained the speeds required for immediate feedback. The trial results further demonstrate that leveraging data analytics within an IoT framework effectively identifies patterns in student learning and athletic achievement.

Discussion

The findings point to three mechanisms through which IoT infrastructure and data analytics improve football learning in higher education. The first is the objectification of performance evaluation, replacing subjective visual observation with sensor-based measurement that yields quantitative data consistent, verifiable, and comparable over time. This is consistent with Batu et al.'s (2025) concept of digitalization of monitoring and Ariyanti et al.'s (2024) affirmation of IoT-based learning optimization. The second mechanism is training program personalization: machine learning algorithms analyze individual performance profiles and generate training recommendations tailored to each student's specific needs and developmental trajectory, echoing findings by Athallah (2025) and Suhendry et al. (2025) on AI-based personalization in higher education. The third is the acceleration of pedagogical feedback; the system delivers performance information in real time or near-real time, enabling lecturers

to intervene promptly and allowing students to adjust their technique immediately based on objective data, consistent with [Akintola et al. \(2025\)](#) finding that intelligent adaptive systems can adjust learning pathways in response to learner performance. [Suhendry et al. \(2025\)](#) emphasized that artificial intelligence in higher education should support personalized learning rather than replace educators. In line with this perspective, the present study found that lecturers remain central to the learning process, while the IoT system enhances pedagogical decision-making through objective performance data. [Muhamad & Sumiah \(2025\)](#) stated that big data implementation enables more accurate decision-making and clearer identification of trends, and this holds in football learning too, where longitudinal data analysis can reveal skill development patterns that would never surface through conventional observation alone. [Sangaji et al. \(2025\)](#) highlighted the growing integration of artificial intelligence in educational research. In line with this development, the present study extends the application of technology-assisted learning into the context of sports education, particularly football learning in higher education. The results also show that a successful Internet of Things implementation depends heavily on the ecosystem being ready. This means that infrastructure, skilled workers, and institutional policies must be in place simultaneously. Looking at the bigger picture, this study makes a tangible contribution to the Smart Campus concept in Indonesian sports education, a domain that has received limited empirical exploration to date. [Palantei et al. \(2024\)](#) demonstrated that technology training and socialization can enhance the academic community's preparedness for intelligent systems.

This research further substantiates this claim by illustrating the practicality and efficacy of Internet of Things (IoT) integration within practice-based football learning, contingent upon the system's design being tailored to local contexts. [Yanto & Sari \(2025\)](#) found that IoT and computer vision training builds students' Industry 4.0 competencies, and a comparable effect appeared here: students who used the system not only improved their football performance but also gained technological literacy that will serve their professional development. [Supriyantono et al. \(2026\)](#) argue that educational institutions need comprehensive strategies to stay relevant in the Industry 4.0 and Society 5.0 era, and that deploying IoT in sports learning is one concrete expression of that, offering universities a genuine competitive edge. That said, the study has limitations worth acknowledging. The system depends on stable network connectivity, the initial cost of sensor devices is relatively high, and lecturers require dedicated training before they can operate the system independently ([Bimantara et al., 2023](#)). This study supports the idea that decisions about infrastructure investments in education should be based on careful assessments of needs and realistic evaluations of costs and benefits. [Nurdiana et al. \(2022\)](#) observed that the enduring success of technology integration in education necessitates comprehensive preparedness; this study corroborates that the sustained functionality of an IoT football learning system is contingent upon institutional dedication, encompassing infrastructure upkeep, continuous lecturer training, and consistent financial support. The ramifications of these findings transcend the specific context of football; they possess wider significance for the digital evolution of sports education within Indonesian higher education. Furthermore, the outcomes observed in this constrained setting imply that analogous methodologies could be replicated and modified for application across various sports and educational institutions nationwide with diverse attributes.

This study contributes to the body of knowledge by providing a systematic framework for the socio-technical integration of IoT within Indonesian higher education sports curricula. It establishes a practical, evidence-based pathway for transitioning from subjective, experience-based sports training to objective, human motion analysis methods. By integrating high-frequency kinematic data with the four-phase training model, this research bridges the gap between theoretical "smart" concepts and the practical demands of the football field. The improvements observed are driven by the objectification of performance, which yields consistent, comparable quantitative data. Personalization further optimizes outcomes by enabling machine learning algorithms to generate tailored recommendations based on

individual developmental trajectories. Finally, the system accelerates the pedagogical feedback loop, enabling athletes to adjust their technique immediately based on objective sensor-validated data.

Limitations of Study

While the initial results are promising, several critical limitations and potential biases warrant a more cautious interpretation. First, the small sample size ($n=12$) presents a "small sample bias," which can lead to an overestimation of classification performance and reduced generalizability to the broader student-athlete population. In elite and university sports research, naturally restricted populations often limit statistical power, potentially inflating reported effect sizes.

Furthermore, the novelty effect likely influenced the results; students in the experimental group may have modified their behavior and increased their effort simply due to the excitement of interacting with advanced wearable technology or the awareness of being monitored. Studies indicate that individuals often show temporary performance improvements when they know they are part of a high-tech intervention. However, these improvements may not be sustainable over the long term. Finally, several confounding variables related to student characteristics were not explicitly controlled. Variation in "student motivation" and "prior experience" in football can significantly impact the rate of skill acquisition and the effectiveness of technology-based feedback. For instance, a student's existing "internal vs. external focus of attention" or their knowledge of the exercise endpoint can lead to meaningful enhancements or deficits in outcome measures independently of the IoT system itself. Future longitudinal studies with larger, more diverse cohorts are necessary to isolate the specific impact of the technology from these psychological and environmental factors.

Conclusions

This study produced three principal findings. First, a four-layer IoT infrastructure architecture for university-level football learning was successfully designed, comprising a wearable sensor and camera-based sensing layer, a private local network with edge computing capabilities, a machine learning-driven processing layer, and a mobile and web application layer for both lecturers and students. Second, a data analytics integration model was developed that covers all four training phases: planning through historical data analysis, implementation through real-time monitoring, control through comparative analysis, and evaluation through longitudinal trend analysis. Third, the field trials demonstrated that the system significantly improved students' technical football performance across all measured indicators with large effect sizes, and received strong feasibility endorsements from coaching, technology, and sports education experts.

On that basis, several recommendations follow. Higher education institutions should consider a phased implementation of IoT systems tailored to their current infrastructure capabilities. Subsequent investigations should employ longitudinal methodologies and broaden this framework's application to diverse sporting domains to assess its generalizability. University administrators would gain from integrating IoT infrastructure into their institutional development master plans, with a focus on data security protocols and proactive collaboration between sports education and information technology departments.

Authors' contributions

MSZ contributed to the research conceptualization, study design, data collection and/or assembly of data, data analysis and interpretation, manuscript writing, critical revision of the article, and final approval of the manuscript. S contributed to the data collection and/or assembly of data, critical revision of the article, and final approval of the manuscript. AZ contributed to the data collection and/or assembly of data, data analysis and interpretation, critical revision of the article, and final approval of the manuscript. All authors reviewed and approved the final version of the manuscript.

Competing interests

The authors declare no competing interests.

AI Disclosure Statement

During the preparation of this manuscript, the authors used Perplexity for language refinement and structural organization of academic content. All AI-generated outputs were critically reviewed and thoroughly edited by the authors to ensure factual accuracy, clarity of expression, and compliance with academic standards. The authors take full responsibility for the integrity and content of this manuscript.

Data Availability Statement

The empirical data supporting the findings of this study are contained within the manuscript and its supplementary materials. Additional detailed datasets or raw data used for the structural equation modeling are available from the corresponding author upon reasonable academic request.

Funding

This research did not receive external funding.

Publisher's Note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or a claim its manufacturer may make, is not guaranteed or endorsed by the publisher.

References

- Ait Ouchtout, W., Zaki, S., & Idrissi Gartoumi, K. (2025). Advancing digital innovation in the AEC industry: A bibliometric analysis on the BIM, AI and IoT integration. *IOP Conference Series: Earth and Environmental Science*, 1499(1), 012010. [[Crossref](#)]
- Akintola, A. S., Akintayo, M., Kadri, T., Oforgu, C. M., Michael, O., & Nwanna, M. (2025). Adaptive AI Systems in Education: Real Time Personalised Learning Pathways for Skill Development. *International Journal of Advance Computational Engineering and Networking*, 3(1), 2489-2494. [[Crossref](#)]
- Al-Atawi, A. A., Alyahyan, S., Alatawi, M. N., Sadad, T., Manzoor, T., Farooq-i-Azam, M., & Khan, Z. H. (2023). Stress monitoring using machine learning, IoT and wearable sensors. *Sensors*, 23(21), 8875. [[Crossref](#)]
- Ariyanti, S., Mustofa, Z., & Mukminin, A. (2024). Optimalisasi Pembelajaran Islam Era Society 5.0 Dengan Pemanfaatan Internet Of Things (Iot). *Ar Rasyiid: Journal of Islamic Studies*, 2(1), 10-20. [[Crossref](#)]
- Athallah, Z. (2025). Penerapan Artificial Intelligence dalam Personalisasi Pembelajaran Daring: Suatu Kajian Informatika dan Ilmu Komputer. *Jurnal Ilmiah Multidisiplin Indonesia*, 1(1), 32-40. [[Crossref](#)]
- Awouda, A., Traini, E., Bruno, G., & Chiabert, P. (2024). IoT-Based Framework for Digital Twins in the Industry 5.0 Era. *Sensors*, 24(2), 594. [[Crossref](#)]
- Batu, F. L., Hani, S., Rini, R., Herlina, H., Efrizah, D., Misdawati, M., ... & Supriono, S. (2025). Digitalisasi Sistem Monitoring Kesehatan dan Infrastruktur Komunitas Berbasis IoT dan Big Data: Pelatihan Daring untuk Masyarakat Tanggap Teknologi. *Journal Liaison Academia and Society*, 5(2), 44-55. [[Crossref](#)]
- Bimantara, E. B., Nugrahanti, F., & Sofyana, L. (2023). Sistem Pendukung Keputusan Pemberian Infrastruktur Pembelajaran Pasca Pandemi Untuk Sekolah Di Lingkup Dinas Pendidikan Kabupaten Madiun Dengan Metode Analytical Hierarchy Process (Ahp) Dan Technique For Order Preference By Similarity To Ideal Sol. *Pilar Teknologi: Jurnal Ilmiah Ilmu Ilmu Teknik*, 8(1), 1-8. [[Crossref](#)]
- Bruno, C., & Canina, M. (2019). Creativity 4.0. Empowering Creativity In The Digital Era. In *DS 95: Proceedings of the 21st International Conference on Engineering and Product Design Education*

- (E&PDE 2019), University of Strathclyde, Glasgow. 12th-13th September 2019. [Crossref]
- Darayseh, A. A. (2025). Exploring the Potential and Concerns of Generative Artificial Intelligence - ChatGPT in Educational Settings: An Analytical Study. *Journal of Scientific Development for Studies and Research (JSD)*, 6(21), 58-72. [Crossref]
- Darmawan, R. W., Irawan, I., & Petriansyah, S. (2025). Analisis Adaptif Zero Trust Architecture (ZTA) Berbasis Machine Learning untuk Deteksi Intrusi pada Jaringan IoT dalam Infrastruktur Kritis. *RIGGS: Journal of Artificial Intelligence and Digital Business*, 3(4), 36-45. [Crossref]
- Gowda, V., Sortur, K., & Mishra, S. (2025). Asset Monitoring System for Educational Labs: An IoT-based Embedded Hardware-Software Integration. *AIJFR-Advanced International Journal for Research*, 6(5), 1-14. [Crossref]
- Gamilla, A. P., Tolentino, A. C., & Payongayong, R. T. (2024). A discernment of round-robin vs SD-WAN load-balancing performance for campus area network. *Bulletin of Electrical Engineering and Informatics*, 13(3), 1832-1838. [Crossref]
- Gulyamov, S. (2024). Intelligent waste management using IoT, blockchain technology and data analytics. In *E3S Web of Conferences (Vol. 501, p. 01010)*. EDP Sciences. [Crossref]
- Hammouri, L. N. M., Alrosan, M., Hamdon, H. M. O., Tashtoush, M. A., Althayneh, Z. L., Al-Momani, A. M., Hawari, A. F., Malkawi, S. H., Neyef Al-Saliti, R. A. M., & Ali Doum, H. M. (2026). Smart campus: Designing a digital environment that supports students' psychological well-being. *Research Journal in Advanced Humanities*, 7(1), 1-20. [Crossref]
- Jeffryes, J. (2025). Mapping Information Literacy Outcomes Across Library Services: Opportunities for Community, Staff Development, and Assessment. *The International Information & Library Review*, 57(1), 80-85. [Crossref]
- Kristinasari, D. A., Pasaribu, E., Juliarta, G. T., Saragih, L. M., Maharani, N., Lestari, R., ... Alvionita, U. (2026). Strategi Optimalisasi Pembelajaran Menggunakan Learning Analytics Berbasis LMS di Sekolah Dasar Kelas IV di SD Negeri 122340. *Jurnal Pendidikan Tambusai*, 10(1), 3400-3404. [Crossref]
- Maulana, H., Muhammad, & Iqbal, M. (2024). Perancangan Framework Pembelajaran Pjok Berbasis lot Dengan Pendekatan Adab Dan Akhlak. *Jurnal Penjaskesrek*, 11(2), 69-83. [Crossref]
- Mohamad, M. H., Zakaria, M. A. Z., Ali, N. I. R. C., Kassim, Z., & Baker, R. (2024). The Influence Of Leadership Skills, It Literacy Skills And Teamwork Ability On Internship Students' Employability: Perception Of Employers' Internship Coordinators. *International Journal Of Entrepreneurship And Management Practises (IJEMP)*, 7(26), 171-182. [Crossref]
- Mohite, G., Bhagat, R., & Jadhav, R. (2025). Big Data Analysis using Cloud Computing: Opportunities, Challenges and Applications. *International Journal for Research in Applied Science and Engineering Technology*, 13(4), 2062-2066. [Crossref]
- Muhamad, A., & Sumiah, A. (2025). Analisis Implementasi Aplikasi Big Data Pada Industri Kesehatan, Keuangan Dan Pendidikan. *Digital Business and Entrepreneurship Journal*, 3(1), 24-35. [Crossref]
- Nasih, M. Z., & Mansur, S. A. (2024). Digital Transformation: The Effect of Learning Management Systems in Developing Employee Digital Competence: Study at A Chemical Company in Gresik. *Jurnal Ekonomi, Bisnis & Entrepreneurship*, 18(2), 604-613. [Crossref]
- Nurdiana, R. S., Maldun, S., & Haslinda, N. (2022). Kebijakan Pembelajaran Daring Sebagai Upaya Study From Home (SFH) Selama Masa Pandemi Covid-19 di Lingkup Sekolah Dasar Kabupaten Luwu Utara. *Publician: Journal of Public Service, Public Policy, and Administrastion*, 1(1), 70-79. [Crossref]
- Orellana, M. H. (2025). *Educating for the Future: Why Universities Must Lead the Way in Ethical and Digital Competence*. Global Academic Network. Carver University. [Crossref]
- Palantei, E., Achmad, A., Syarif, S., Arief, A., Rachmaniar, I., Hasanuddin, Z., Panggalo, S., Waris, T., Achmad, A., Baharuddin, M., & Palantei, I. (2024). Sosialisasi dan Pelatihan Teknologi Tatakelola Perkuliahan Berbasis Smart Things. *JURNAL TEPAT : Teknologi Terapan Untuk Pengabdian*

Masyarakat, 7(1), 179-186. [[Crossref](#)]

- Rishard, M. A. M., Jayasekara, S. L., Ekanayake, E. M. P. U., Wickramathilake, K. M. J. S., Reyal, S., Manathunga, K., & Wickramarathne, J. (2022, December). Adaptivo: A personalized adaptive e-learning system based on learning styles and prior knowledge. In *2022 Seventh International Conference on Informatics and Computing (ICIC)* (pp. 1-9). IEEE. [[Crossref](#)]
- Romeral, P. A. de A. F., Spinola, M. de M., Gonçalves, R. F., & Zancul, E. (2021). Development of managerial and Information Technology skills in Learning Factories in the context of Industry 4.0: A case study. *Revista Gestão da Produção Operações e Sistemas*, 16(2), 195–195. [[Crossref](#)]
- Saha, R. (2025). Towards Intelligent Forestry: Big Data, Machine Learning, and Sustainable Management Strategies. *Environment and Ecology*, 43(4), 1111-1121. [[Crossref](#)]
- Sangaji, M. A., Berliana, M., Apriliani, P., Rijoice, M., Simanungkalit, R. R., Stiawan, R. A., & Suryana, A. L. (2025). Kajian Sistematis: Implementasi Ai Dalam Penelitian Pendidikan Sains Di Era Pembelajaran Digital. *EDUTECH : Jurnal Inovasi Pendidikan Berbantuan Teknologi*, 5(4), 802–810. [[Crossref](#)]
- Simanjuntak, R. P., & Sijabat, R. R. M. (2024). Meningkatkan Keamanan Siber dalam Lingkungan Internet of Things (IoT) dengan Menggunakan Sistem Deteksi Intrusi Berbasis Pembelajaran Mesin. *Dike: Jurnal Ilmu Multidisiplin*, 2(2), 62–68. [[Crossref](#)]
- Suhendry, B., Nida, R. R., & Atmadja, F. S. (2025). Kecerdasan Buatan Dalam Personalisasi Pembelajaran Perguruan Tinggi: Inovasi, Peluang, Dan Tantangan Masa Depan. *Al-Irsyad: Journal of Education Science*, 4(2), 825–835. [[Crossref](#)]
- Supriyantono, A., Wajo, M. J., & Widayati, T. W. (2026). Universities In The Era Of Industry 4.0 And Society 5.0: Challenges, Strategies, And Implementation In Indonesia. *Jurnal Abdisci*, 3(3), 356–363. [[Crossref](#)]
- Yanto, S., & Sari, P. I. (2025). The Implementasi Pelatihan Computer Vision dan (IoT) untuk Meningkatkan Kompetensi Industri 4.0 pada Siswa SMK Negeri 9 Bandar Lampung. *Sarwahita*, 22(01), 109-119. [[Crossref](#)]
- Yao, X. (2026). The Influence of VR-Based Interaction Modalities on College Students' Acquisition of Theoretical Medical Knowledge: An Experimental Study Validation. *IEEE Access*, 14, 3426–3437. [[Crossref](#)]