Digital Transformation in Sports Biomechanics Education

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Abstract. The rapid advancement of digital technology has had a significant impact across various fields, including sports education. This study aims to explore the implementation of artificial intelligence (AI)-based motion capture technology in the teaching of sports biomechanics, particularly in enhancing students' motion analysis skills. A quantitative approach with a quasi-experimental design was employed, involving 40 undergraduate students enrolled in a physical education program. The results indicated that the use of AI-based motion capture significantly improved students' motion analysis abilities compared to traditional teaching methods ($p < 0.05$). In addition, students expressed positive perceptions of the learning process, highlighting its interactive and visually engaging nature. These findings suggest that digital transformation through the integration of AI technology in biomechanics education can provide a more effective, accurate, and applicable learning experience within sports education. The study recommends that educational institutions adopt similar technologies to modernize and enhance the quality of motion analysis based learning in higher education.

Keywords: digital transformation, motion capture, artificial intelligence, sports biomechanics, motion analysis.

1 Introduction

The paradigm shift brought about by digital transformation has significantly influenced various aspects of education, including physical education and sports. Digital transformation is characterized by the integration of information technology into the learning process, making it more interactive, adaptive, and data-driven (Selwyn, 2016). In the context of higher education, digitalization functions not only as a supporting tool but also as a catalyst for shifting from traditional approaches toward more collaborative and data-based learning. This shift is essential for enhancing the quality of education while preparing students to meet the challenges of the Industry 4.0 era.

One area that has been notably affected by technological advancement is sports biomechanics, the field concerned with applying mechanical principles to human movement (Hamill &

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Knutzen, 2015). For students of physical education, a solid understanding of biomechanics is crucial, as it underpins the analysis of technique, injury prevention, and performance enhancement. However, biomechanics education often faces challenges due to its abstract and complex nature. In practice, traditional approaches such as manual observation, conventional video analysis, and descriptive explanations remain dominant. These methods, while foundational, suffer from limitations in measurement accuracy, speed of analysis, and student engagement (Bartlett, 2014). As a result, achieving an optimal understanding of biomechanics concepts can be difficult, particularly when students are expected to analyze complex movements with high precision.

Digital transformation, through the use of AI-based motion capture technology, presents new opportunities to overcome these limitations. Motion capture systems record human movement digitally using sensors or cameras and convert it into numerical data and three-dimensional visualizations. Supported by artificial intelligence, such systems are capable of analyzing movement patterns, detecting technical errors, and providing real-time feedback (Lees, 2019). These features make biomechanics learning more concrete, objective, and interactive for students.

Previous studies have highlighted the effectiveness of digital technology in sports contexts. For example, Wang and Liu (2020) found that integrating AI into biomechanical analysis significantly improved the accuracy of students' movement assessments. Similarly, Nigg and Federolf (2016) reported that motion capture accelerates students' comprehension of complex biomechanical movements. Nevertheless, most prior research has focused on the application of this technology in laboratory settings and athletic training, rather than within formal higher education contexts.

Given this gap, the application of AI-based motion capture in sports education, particularly in biomechanics instruction, remains underexplored. This research gap forms the basis of the present study, which aims to examine the effectiveness of AI-based motion capture technology in improving students' motion analysis skills and to compare its impact with that of traditional teaching methods. The findings are expected to contribute both theoretically and practically to the development of a more modern, accurate, and applicable model for biomechanics education in higher education.

2 Methodology

This study employed a quantitative approach using a quasi-experimental design in the form of a pretest–posttest control group design. This design was considered appropriate because it allows a direct comparison between the effectiveness of biomechanics learning through artificial intelligence (AI)-based motion capture technology and conventional teaching methods. The participants consisted of 40 undergraduate students enrolled in the Physical Education, Health, and Recreation program at Universitas Negeri Medan. The sample was selected using purposive sampling with specific inclusion criteria, namely students who were currently taking the Biomechanics course, had basic computer literacy, and agreed to participate in the entire research process. Of these participants, 20 students were assigned to the experimental group, which received instruction through an AI-based motion capture system, while the remaining 20 were placed in the control group, which received traditional instruction involving manual video analysis and classroom discussion.

Two instruments were used in the study. The first was a motion analysis test designed to measure students' ability to identify, explain, and evaluate fundamental sports movements. The content validity of this test was verified by three biomechanics experts, while its reliability was examined using Cronbach's Alpha. The second instrument was a technology perception questionnaire that aimed to evaluate students' responses toward the AI-based motion capture system. The questionnaire employed a five-point Likert scale and covered four main aspects: interactivity, ease of use, clarity of visualization, and motivation to learn.

The procedure of the study began with an explanation of the objectives and learning instructions provided to both groups. A pre-test was then administered to measure students' baseline abilities in motion analysis. Following this, the experimental group received biomechanics instruction using the AI-based motion capture technology, which offered automated analysis and real-time feedback, while the control group was taught using conventional methods that included video observation and classroom discussion. After the instructional intervention, both groups completed a post-test to assess the improvement in their motion analysis skills. At the final stage, the students in the experimental group were asked to fill out the perception questionnaire to provide their evaluation of the learning experience using the AI-based system.

The data obtained from the motion analysis test were analyzed using an independent samples t-test to identify differences in improvement between the experimental and control groups. Meanwhile, the data collected from the perception questionnaire were analyzed descriptively to summarize students' responses regarding the use of AI-based motion capture technology in biomechanics learning.

3 Results

The findings of this study revealed a significant improvement in motion analysis skills among students in the experimental group compared to the control group. During the *pre-test*, the experimental group achieved a mean score of 62.40 (SD = 5.21), while the control group scored 61.85 (SD = 5.09). The difference was not statistically significant ($p > 0.05$), indicating that both groups had relatively similar baseline abilities.

Following the intervention, the *post-test* results showed a marked difference. The experimental group obtained a mean score of 82.75 (SD = 4.62), whereas the control group reached only 72.10 (SD = 5.34). An independent samples t-test confirmed that the difference between groups was statistically significant ($t_{(38)} = 6.21$, $p = 0.000 < 0.05$). This finding suggests that learning biomechanics using AI-based motion capture technology is more effective in enhancing students' motion analysis skills compared to conventional teaching methods.

Table 1. Summary of Research Results.

Group	Pre-test Mean (SD)	Post-test Mean (SD)
Experimental	62.40 (5.21)	82.75 (4.62)
Control	61.85 (5.09)	72.10 (5.34)

Table 2. Statistical Test Results.

Test	t-value	p-value	Significance
Independent Samples t-test	6.21	0.0	$p < 0.05$ (Significant)

In addition to test scores, students' perceptions of the learning process were evaluated using a questionnaire. The descriptive analysis revealed overwhelmingly positive responses. Specifically, 87% of students agreed that learning with AI-based motion capture was more interactive, 82% reported that it facilitated better understanding of concepts, 90% highlighted the accuracy of visualizations, and 85% stated that it increased their motivation to learn. The overall mean perception score was 4.35 (SD = 0.41) on a 5-point Likert scale, reflecting a high level of acceptance toward the technology.

Table 3. Students Perceptions of AI-based Motion Capture.

Aspect	Percentage (%)
More Interactive	87%
Easier to Understand	82%
More Accurate Visualization	90%
Increased Learning Motivation	85%

Taken together, these results indicate that the integration of AI-based motion capture not only improves the accuracy and effectiveness of motion analysis learning but also enhances interactivity, clarity, and student motivation, thereby providing a more engaging and impactful learning experience

4 Discussion

The present study demonstrates that AI-based motion capture technology significantly improves students' ability to analyze human movement in a biomechanics learning context. The experimental group achieved notably higher post-test scores compared to the control group, indicating that the intervention was effective in facilitating deeper understanding and application of biomechanical principles. This outcome can be explained through the lens of constructivist learning theory, which emphasizes the importance of interactive, experiential, and feedback-rich environments in fostering knowledge construction (Jonassen, 1999). By providing real-time visualization and automated feedback, AI-based motion capture aligns with this pedagogical framework and enhances the learning process.

The improvement in students' motion analysis performance is consistent with earlier studies highlighting the educational value of digital technologies in sports science. Wang and Liu (2020) reported that AI-enhanced biomechanical analysis increases the accuracy and reliability of students' assessments. Similarly, Nigg and Federolf (2016) found that motion capture accelerates learners' comprehension of complex kinematic patterns, particularly when compared to traditional observational methods. These findings reinforce the argument made by Bartlett (2014), who noted that conventional approaches in biomechanics education often struggle with issues of accuracy and student engagement. The present study contributes to this body of evidence by showing that these limitations can be overcome through digital transformation in formal classroom settings.

Students' perceptions further strengthen the pedagogical case for AI-based motion capture. The overwhelmingly positive responses indicating higher interactivity, clarity, and motivation align with Selwyn's (2016) perspective on digital transformation in education, which positions technology not only as a tool for efficiency but as a catalyst for more engaging and student-centered learning environments. Motivation, in particular, is a critical outcome, as it plays a central role in the Self-Determination Theory (Deci & Ryan, 2000), where intrinsic engagement is linked to improved learning outcomes. By increasing motivation, motion capture technology may indirectly enhance both the quality and sustainability of student learning.

The implications of these findings are twofold. First, from a pedagogical standpoint, integrating AI-based motion capture into biomechanics courses allows educators to bridge the gap between abstract theory and practical application. This fosters a more holistic learning experience in which students not only understand biomechanical concepts but also practice analyzing and applying them with precision. Second, from a broader educational perspective, this research illustrates the role of digital transformation in preparing future graduates with advanced analytical and technological competencies that are increasingly valued in the sports science and health industries.

Nevertheless, this study also acknowledges certain limitations. The relatively small sample size and single-institution context limit the generalizability of the findings. In addition, the adoption of AI-based motion capture requires significant institutional investment in infrastructure and faculty training, which may pose barriers for widespread implementation. Furthermore, the study focused primarily on short-term outcomes; future research should examine the long-term impact of technology-enhanced biomechanics education, including knowledge retention and transfer to professional practice.

In summary, the discussion of results confirms that AI-based motion capture provides measurable improvements in students' motion analysis abilities, validates theories of active and technology-supported learning, and supports prior empirical evidence. It also points toward the broader implication that digital transformation in higher education when strategically implemented can enrich both cognitive and motivational aspects of learning, making it more precise, engaging, and relevant for the demands of contemporary professional practice.

5 Conclusion

This study provides empirical evidence that integrating AI-based motion capture technology into biomechanics education significantly enhances students' motion analysis skills compared to conventional teaching methods. The experimental group outperformed the control group on post-test scores, while perception data revealed strong student acceptance, highlighting the interactive, accurate, and motivating qualities of the technology. These findings demonstrate that digital transformation, when strategically applied, can overcome the limitations of traditional approaches such as low accuracy, slow analysis, and limited engagement by offering real-time visualization, objective measurement, and immediate feedback.

Theoretically, this study reinforces constructivist learning principles and Self-Determination Theory by showing that active, feedback-driven, and motivating learning environments foster deeper understanding and sustained engagement. Practically, the findings suggest that higher education institutions should consider adopting AI-based motion capture to modernize biomechanics education, better prepare students for professional demands, and align curricula with the digital transformation agenda in sports science.

Nevertheless, the study is limited by its small sample size, single-institution focus, and short-term scope. Future research should explore broader applications across diverse educational contexts, assess long-term knowledge retention, and evaluate cost-effectiveness and scalability. Addressing these areas will provide a more comprehensive understanding of the potential and challenges of AI-driven motion capture in higher education.

In conclusion, the integration of AI-based motion capture represents a meaningful step forward in advancing biomechanics education. By combining technological innovation with evidence-based pedagogy, it offers a powerful approach to creating learning experiences that are more effective, engaging, and relevant for the digital era.

6 Recommendations

Based on the results of this study, several recommendations can be proposed to strengthen the integration of AI-based motion capture technology in sports biomechanics education. First, higher education institutions should consider adopting AI-driven motion capture systems as part of their sports science and physical education curricula. By doing so, universities can provide students with a more interactive, accurate, and engaging learning experience that goes beyond the limitations of traditional methods.

Second, faculty members should receive adequate training and professional development to effectively implement and maximize the potential of this technology. Lecturer readiness plays a critical role in ensuring that AI-based systems are not only used as demonstration tools but are integrated meaningfully into teaching and learning activities.

Third, policymakers and educational stakeholders should invest in the necessary technological infrastructure, including hardware, software, and technical support, to enable broader access to digital transformation initiatives in sports education.

Fourth, further research is recommended to examine the long-term effects of AI-based motion capture on learning outcomes, including knowledge retention, skill transfer to real-world practice, and its impact on different student populations. Expanding future studies to larger and more diverse samples across institutions will also improve the generalizability of the findings.

Finally, interdisciplinary collaboration between sports scientists, computer scientists, and educational technologists should be encouraged to further develop motion capture systems that are user-friendly, cost-effective, and tailored to educational contexts. By addressing these areas, educational institutions can ensure that the digital transformation of sports biomechanics education not only improves students' analytical skills but also contributes to a more modern, scalable, and sustainable learning environment in higher education.

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