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Development of augmented reality-based musculoskeletal system anatomy learning modules to improve learning outcomes of physical education students

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Abstract

Anatomy is a fundamental subject in physical education because understanding the human musculoskeletal system is crucial for effective sports practice, rehabilitation, and teaching physical activities. However, traditional teaching methods relying on lectures, textbooks, and 2D illustrations often fail to develop students' spatial comprehension, leading to low academic performance. Augmented Reality (AR) has been identified as a potential solution to enhance engagement, motivation, and learning outcomes. This study aimed to develop and evaluate an AR-based learning module for the musculoskeletal system, integrated with VisioBody, to improve cognitive, affective, and psychomotor learning outcomes in physical education students. This research employed a Research and Development (R&D) approach using the ADDIE model (Analyze, Design, Development, Implementation, Evaluation). The subjects were 70 second-semester students of the Physical Education, Health, and Recreation Program at Universitas Hamzanwadi, divided into experimental (n=35, AR-based module) and control groups (n=35, conventional module). Data collection included expert validation (content, media, and language), practicality questionnaires, and learning outcome tests covering cognitive (multiple choice), affective (observation), and psychomotor (performance test) domains. Data analysis used the Kolmogorov-Smirnov test for normality, Levene's test for homogeneity, and one-way ANOVA to evaluate differences between groups. Validation results showed the module was highly valid (CVI=0.97). Practicality testing indicated high acceptance, with scores above 90% from both students and lecturers. Effectiveness testing revealed significant differences between experimental and control groups across all domains: cognitive ($F=21.414$; $p<0.05$), affective ($F=21.414$; $p<0.05$), and psychomotor ($F=20.934$; $p<0.05$). Students in the AR-based group achieved higher average scores (76.59) compared to the control group (68.08). The AR-based anatomy module proved valid, practical, and effective in improving students' cognitive understanding, affective engagement, and psychomotor skills. This innovation offers a feasible solution to overcome the lack of anatomy laboratories and aligns with 21st-century learning needs for interactive and immersive educational strategies.

Keywords: Augmented Reality, Anatomy learning, Musculoskeletal system, Physical education, Multimedia learning, Learning outcomes

Introduction

Anatomy is the main foundation in the fields of health science and physical education because a good understanding of the structure and function of the human body greatly determines the effectiveness of sports practice, rehabilitation, and physical activity teaching. However, anatomy education in higher education still faces major challenges globally. The complexity of abstract, detailed, and spatial material makes it difficult for students to understand the relationship between bones, muscles, and joints by relying solely on conventional methods such as lectures, textbooks, and two-dimensional illustrations [1,2]. This makes it easier for students to remember anatomical terms, but difficult to connect theoretical concepts with the practical skills required in the fields of health and sports.

Several studies indicate that the use of conventional media is insufficient to provide a deep spatial understanding of the musculoskeletal system. Triepels et al. Three-dimensional visualisation can improve knowledge retention and analytical skills among anatomy students compared to traditional 2D media [3,4,5]. Similarly, Krüger et al. Integration of Augmented Reality (AR) technology is highly effective in strengthening spatial understanding, increasing learning motivation, and reducing students' cognitive load [6,7,8]. Neri et al. AR not only supports the achievement of cognitive learning outcomes, but also enhances students' affective engagement through more immersive and interactive learning experiences [9,10]. These findings confirm that the need for technology-based media innovation, particularly AR, is highly relevant to improving the quality of anatomy learning in higher education.

In the Indonesian context, the challenges of learning anatomy are becoming increasingly apparent due to the limited availability of anatomy laboratories in many universities, including those offering physical education programmes. The learning process still relies heavily on lectures, textbooks, and two-

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dimensional images, which has resulted in low learning outcomes among students. Data from the Hamzanwadi University Quality Assurance Institute shows that in the last two years, student achievement in anatomy courses has remained below the expected standard, particularly in the areas of conceptual understanding and movement analysis skills. This fact emphasises the need for innovative learning media based on immersive technologies such as AR, which are relevant to the characteristics of Generation Z, who are accustomed to digital devices and visual-kinesthetic learning [11,12,38].

Augmented Reality (AR) is an innovative solution that can interactively display anatomical objects in three dimensions. This technology helps students visualise the structure of muscles, bones and joints from various angles, thereby strengthening spatial understanding and practical skills that were previously difficult to achieve with conventional media. The immersive visualisation provided by AR also supports active learning by placing students as participants who are directly involved in exploring the material. A number of studies have demonstrated the effectiveness of AR in improving students' conceptual understanding, motivation, and knowledge retention. The use of AR in anatomy learning strengthens students' emotional and cognitive engagement [13,14]. AR integration can improve spatial understanding and encourage more meaningful learning interactions [15,16]. Similar results were found who reported that students who used AR in anatomy studies had higher learning outcomes than the control group who used traditional methods [17,18]. A recent meta-analysis also concluded that AR is effective in reducing students' cognitive load by presenting information through visual and verbal channels simultaneously [19]. AR is not merely a technological innovation, but rather a pedagogical necessity for addressing the challenges of complex anatomy learning in the era of digital education.

Based on this urgency, this study focuses on the development of an AR-based musculoskeletal anatomy learning module integrated with the VisioBody application. The main objective of this study was to examine the validity, practicality, and effectiveness of the module in improving the learning outcomes of Physical Education students, covering the cognitive, affective, and psychomotor domains. From a theoretical perspective, this study contributes to the reinforcement of multimedia learning theory (Mayer, 2021) and cognitive load theory by demonstrating how AR can reduce cognitive load while improving spatial concept understanding in anatomy. From a practical standpoint, these findings are expected to provide concrete solutions to the limitations of anatomical laboratory facilities, which remain a major obstacle in many universities in Indonesia. AR through the VisioBody module can be an alternative virtual laboratory that is easily accessible to Generation Z students who are accustomed to digital technology and visual-kinesthetic-based learning [20,21,37]. This research also supports the transformation of higher education towards a more interactive, flexible, and adaptive 21st-century learning model. As stated by Silén et al. (2022), the integration of advanced visualisation technology in anatomy learning not only improves learning outcomes but also creates a more authentic learning experience.

The novelty of this research lies in the development of an Augmented Reality (AR)-based learning module on the musculoskeletal system, which is integrated with a printed module through the VisioBody application, resulting in a hybrid learning package that combines the advantages of traditional media with technology. Unlike previous studies that focused more on the use of AR applications separately or based solely on digital simulations, this study presents a systematic module design based on the ADDIE model, comprehensively validated by content, media, and language experts, and tested for practicality and effectiveness through experiments on Physical Education students.

The integration of AR in this module is not only intended to enrich spatial visualisation, but is also designed to improve overall learning outcomes in the cognitive, affective, and psychomotor domains, which are rarely the focus of similar research. This research makes an important contribution in providing innovative solutions to the limitations of anatomy laboratories in Indonesia, while also expanding empirical studies on the application of AR in physical education, which was previously limited to the fields of health and medicine.

Methods

This study utilised a Research and Development (R&D) approach with the ADDIE model (Analyse, Design, Development, Implementation, Evaluation) developed by Dick, Carey, and Carey [22] due to its systematic, dynamic, and adaptive nature in producing quality learning products. The ADDIE stages include analysing student needs and characteristics, designing AR-based modules, development and validation by experts, implementation through small and large group trials and experimental classes, and formative and summative evaluations to assess the validity, practicality and effectiveness of the modules.

The subjects of this study were 70 second-semester students majoring in Physical Education, Health, and Recreation (PJKR) at Hamzanwadi University, divided into two groups: an experimental group of 35 students who studied using AR-based anatomy modules and a control group of 35 students who studied using conventional modules without AR. In addition, this research also involved a validation team consisting of seven experts, including content experts, media experts, and language experts, to assess the feasibility of the developed modules.

The module development procedure at the *Analyse* stage includes identifying requirements, which show that 73.09% of anatomy learning resources are still in the form of printed books, with modules accounting for only 1% and AR media not yet in use. Curriculum analysis was conducted by examining the Semester Learning Plan, Course Learning Outcomes, and learning outcomes, while student character analysis showed that the majority of Generation Z students have a visual-spatial learning style and are accustomed to technologyIn addition, an analysis of the learning environment found that the PJKR study programme does not yet have an anatomy laboratory, but all students have Android smartphones that support the use of AR.

At the *Design* stage, a module outline is compiled that includes learning objectives, indicators, concept maps, material on the anatomy of the musculoskeletal system, practice questions, and evaluations. The technology selected for the development of this module is based on VisioBody, Unity 3D, and Vuforia engine to support optimal Augmented Reality integration. The instructional design refers to the Multimedia Learning theory [23] by combining text, images, and AR visualisations to make the presentation of material more interactive, contextual, and able to improve students' understanding.

In the *Development* stage, researchers compiled an initial product in the form of an Augmented Reality (AR)-based anatomy module that integrates musculoskeletal anatomy material with AR markers to generate three-dimensional objects. This initial product was validated by experts, namely content experts, media experts, and language experts. Based on the validation results, product revisions were made in accordance with the input and suggestions from the validators so that the resulting modules were more in line with academic standards, practical to use, and relevant to student needs. The expert evaluation-based development process contributes significantly to the effectiveness of AR media in anatomy learning.

During the *Implementation* stage, the AR-based anatomy module was tested through three stages: a small group trial with 15 students and 5 lecturers to assess readability and practicality, a large trial with 25 students and 7 lecturers to ensure consistency, and a field trial in two classes, namely experimental (using AR) and control (conventional) to see the difference in learning outcomes.

The *Evaluation* stage was conducted formatively through expert validation, limited trials, and revisions, as well as summatively using a posttest-only nonequivalent control group design to test the effectiveness of AR-based modules in improving student learning outcomes.

Hypothesis testing (independent t-test)

$$X = \frac{X_1 - X_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

The statistical hypothesis used is as follows:

H_0 : $\mu_1 = \mu_2$ → there was no difference in learning outcomes between the experimental group and the control group. $H_1 : \mu_1 \neq \mu_2$ → there was a significant difference in learning outcomes between the experimental group and the control group. If the significance value (Sig.) is 0.05, then H_0 is rejected and H_1 is accepted, meaning that the Augmented Reality-based module is effective in improving learning outcomes compared to conventional modules.

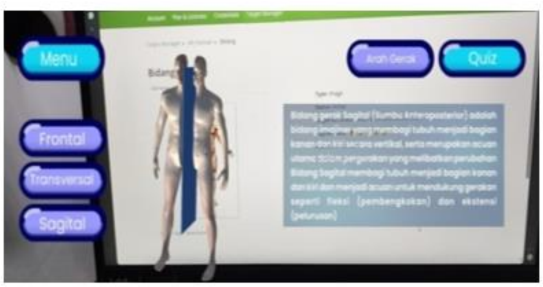
Result

Development of the VisioBody AR application

The development of the augmented reality (AR) application VisioBody is one of the technology-based learning innovations that combines three-dimensional visualisation with direct user interaction to study the anatomy of the body in a more realistic and in-depth manner. This application is designed to provide an immersive learning experience through anatomical models that can be rotated, enlarged, and viewed from various angles, making it easier for students to understand the structure, function, and interrelationships between different parts of the body.

The VisioBody start screen displays the Scan, About, Help, and Exit menus for detecting markers, viewing developer information, usage guides, and exiting the application.

Figure 1. Initial menu display of the visiobody application

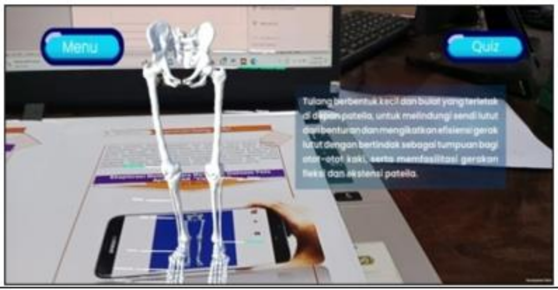


The first screen displays a menu with Menu to return to the home page, Frontal, Transversal, and Sagittal for explanations of body parts and their animations, Direction of Movement for body movement animations, and Quiz for interactive evaluation questions.

Figure 2. Display of anatomy material and body movement direction

The second screen displays a menu Menu to return to the home page, Text on Arrows for explanations and exploration of the bones and joints of the upper body, and Quiz for interactive evaluation questions..

Figure 3. Display of the second material: Anatomy of the passive musculoskeletal system of the lower body

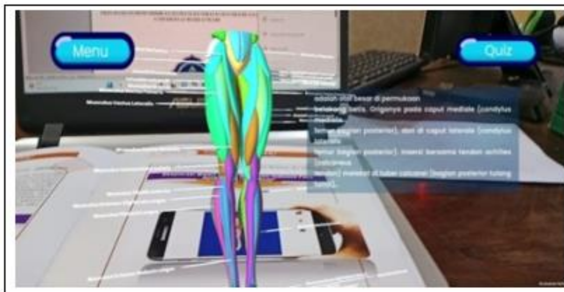


The third screen displays a menu with Menu to return to the home page, Text on Arrow for explanations and exploration of the bones and joints of the lower body, and Quiz for interactive evaluation questions.

Figure 4. Display of the third material: anatomy of the passive musculoskeletal system of the lower body

The fourth screen displays a menu with Menu to return to the home page, Text on Arrow to explain and explore the major muscles of the upper body, and Quiz to display interactive evaluation questions.

Figure 5. Display of the fourth material on the anatomy of the upper active muscular system of the body



The fourth screen displays a menu Menu to return to the home page, Text on Arrow for explanations and exploration of the main muscles of the lower body, and Quiz for interactive evaluation questions.

Figure 6. Display of material five anatomy of the lower body active movement system

AR-Assisted Module Design Validation

Validity was assessed using the content validity ratio (CVR) and Content Validity Index (CVI) methods, employing Lawshe's (1975) approach. During the implementation phase, the AR module and media design were validated by six experts consisting of content experts, media experts and language experts. Validation was carried out on the learning outcome instruments and products (learning modules with AR application *VisioBody*). Details of the validation results and suggestions for improvement in each aspect can be seen in the following table:

Table 01. Expert validation of AR-Assisted anatomy learning module visiobody

Aspect	Number of Experts	CVR value	CVI value	Kategori	Suggestions for Improvement
Media	6	0.83	0.92	Valid	The cover design and guide are combined in a printed module, while the VisioBody application is tailored to the course and enhanced with graphics

					and marker responsiveness for optimal performance on Android.
Accounts Materi	6	1	1	Very Valid	Add AR-based interactive evaluation questions and use motion animations with real models in the material.
Language	6	1	1	Very Valid	Correct anatomical terms and typographical errors
Average	6	0.94	0.97	Very Valid	

Practicality

The practicality of the module was evaluated through trials conducted in two stages, namely small groups (limited scale) and large groups (broad scale). Small group trials aim to obtain an initial overview of the comprehensibility of content, clarity of instructions, and ease of use of the module by students within a limited scope. The results of this stage form the basis for making initial improvements before the module is implemented more widely.

Table 1. Results of the practicality test of the AR-assisted anatomy learning module visiobody app in small groups

No	Subject	Average	Kategori
1	5 Lecturer	91.2	Very practical
2	15 student	92,4	Very practical

Practicality test large group practicality test

Large-scale practical testing plays an important role in confirming the quality of modules as learning tools that are not only suitable for use, but also effective and relevant to learning needs in the field.

Table 2. Results of the practicality test of the AR-assisted anatomy learning module apk visiobody in large groups

No	Subject	Average	Kategori
1	7 Lecturer	93.6	Very practical
2	25 students	92,64	Very practical

Effectiveness of ar technology-assisted modules

Uji hipotesis

The use of AR modules on learning outcomes (*cognitive, psychomotor*and*affective*) before and after between the control class (conventional module) and the experimental class (AR module), the analysis used to test the researcher's hypothesis wasone-way ANOVA test(one-way ANOVA).

Nilai kognitif

Tabel 3. One-way anova for kognitif domain

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	79.696	20	13.985	21.414	.000
Within Groups	532.804	189	2.819		
Total	612.500	209			

The results of the analysis in the cognitive domain show that the F value is 21.414 with a significance value (Sig.) of 0.000. Since the significance value is smaller than the α level = 0.05, it can be concluded that there is a significant difference between the groups in terms of cognitive learning outcomes. These findings indicate that the treatment provided, namely the use of technology-assisted anatomy modules using augmented reality (AR), has a significant effect on improving students' cognitive learning outcomes

Value affective

Tabel 4. One-way anova for apektif domain

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	79.696	3	13.985	21.414	.000
Within Groups	532.804	189	29.819		
Total	612.500	236			

The results of the analysis in the affective domain showed that the F value was 21.414 with a significance value (Sig.) of 0.000. Since the significance value is smaller than the α level = 0.05, it can be concluded that there is a significant difference between the groups in terms of students' affective learning outcomes. The use of augmented reality (AR) technology-assisted anatomy modules has had a significant impact on improving students' attitudes, interest and motivation to learn.

Value psychomotor

Table 5. One-way ANOVA for the psychomotor domain

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2745.000	3	1462.431	20.934	.000
Within Groups	5661.841	215	77.146		
Total	1833.674	216			

Based on the results of the psychomotor domain analysis, the calculated F value was 20.934 with a significance value (Sig.) of 0.000.

Since the significance value was smaller than the α level of 0.05, it can be concluded that there was a significant difference between the groups in terms of students' psychomotor learning outcomes.

Differences in learning outcomes

The following hypothesis test results confirm that the use of ART-assisted modules has great potential to improve the quality of the learning process and outcomes when compared to traditional learning approaches.

Table 6. Differences in learning outcomes between the experimental class and the control class

Dependent Variable: Skor Perolehan				
			99% Confidence Interval	
Jenis Kelas	Mean	Std. Error	Lower Bound	Upper Bound
Kelas Eksperimen	76,593	,903	74,246	78,940
Kelas Control	68,085	,928	65,672	70,498

From this data, the average score of the experimental class (76.59) is greater than the average score of the control class (68.08), so it can be concluded that the experimental class is better than the control class.

Discussion

The module design is aimed at providing innovative learning tools that can visualise anatomical systems in an interactive and practical manner, thereby addressing the limitations of anatomical laboratories in many universities. Product validation is carried out by experts to ensure the suitability of content, media quality, and language with learning outcomes, while practicality tests examine readability and ease of use from the perspective of both students and lecturers. In the final stage, the effectiveness of AR-based modules is tested to see the extent to which the modules can improve students' cognitive, affective, and psychomotor learning outcomes.

The design process for the musculoskeletal system anatomy module utilised the VisioBody application, which enables the integration of interactive 3D representations. This module was developed in two forms: a printed module as the main guide and an AR application as a digital supplement. The printed format is equipped with *markers* that can be scanned using Android or iOS devices, producing a 3D visualisation of bones, muscles and joints instantly. This innovation is relevant to the research [24,25] that AR helps improve spatial understanding and knowledge retention among anatomy students. AR integration is a strategic solution for educational institutions with limited laboratory facilities, as it provides interactive simulations that resemble real-life practices [26,27].

The design of this module is also based on Cognitive Load theory and Mayer's multimedia learning theory (2022), which emphasises the simultaneous presentation of visual and verbal information to reduce students' cognitive load. AR features such as rotation, zoom, and interactive identification have been shown to strengthen cognitive schemas and spatial understanding [28]. Shows that AR can significantly increase motivation, engagement, and understanding of anatomical topography, making it a relevant learning medium for digital generation students [29].

Validation is carried out by subject matter, media and language experts to assess the suitability of the modules. The content aspect was validated based on its suitability with the curriculum and learning outcomes, resulting in a very high Content Validity Index (CVI) score (0.94–0.97), indicating the accuracy of the module content. Media validation assessed visual integration, ease of use, and accessibility, all of which showed high feasibility, that the success of AR media is determined by the integration of the interface with digital content [30]. Language validation also received a very high score, with results showing that the communicative module's language style, using clear scientific terms, was appropriate for the students' level of understanding.

The results of small group trials (15 students, 5 lecturers) and large group trials (25 students, 7 lecturers) showed that this module falls into the "very practical" category, with a practicality score of >85%. Students stated that the module was easy to use, aided visualisation, and increased motivation to learn, while lecturers assessed that the module supported teaching effectiveness. These results are in line with the research [31,32] which confirms that AR accelerates the understanding of complex concepts through a visual-kinesthetic approach. This high level of practicality is also supported who emphasise the importance of user-centred design in order for digital media to be more easily accepted by users [33].

Effectiveness analysis using ANOVA tests showed significant differences between the experimental group (AR module) and the control group (conventional module) in cognitive, affective, and psychomotor aspects. These results reinforce Mayer's (2022) multimedia theory and the principle of constructivism, which emphasises the importance of students' active involvement in constructing meaning. Research found that AR outperformed traditional methods in improving understanding of anatomical structures [33], while a study by Zhang et al. (2024) showed that AR strengthened students' spatial and problem-solving skills. From an affective perspective, research [34,35] confirms that AR significantly increases student motivation and participation. Psychomotorically, AR provides a learning experience similar to laboratory practice, enabling students to become more skilled at identifying anatomical structures [36].

Conclusion

This study aims to develop an Augmented Reality (AR)-based learning module on the anatomy of the musculoskeletal system to improve the learning outcomes of Physical Education students. The results showed that the developed module was valid, practical, and effective. The validity of the module was supported by the results of content, media, and language expert tests with a Content Validity Index (CVI) score reaching the *highly valid* category (0.94–0.97), confirming the suitability of the material, the integration of media, and the clarity of language. From a practical standpoint, trials on both small and large groups scored above 90%, indicating that the module is very easy to use, supports interactivity, and increases student motivation to learn.

The effectiveness of the module was tested using one-way ANOVA, with results showing significant differences in the cognitive, affective, and psychomotor domains between the experimental group (AR module) and the control group (conventional module), with a significance value of $p<0.05p < 0.05p<0.05$. These findings prove that the use of AR-based modules can strengthen conceptual understanding, improve learning attitudes and motivation, and improve students' anatomical identification skills. The average score of students in the experimental class (76.59) was higher than that of the control class (68.08), confirming the superiority of AR modules over traditional methods.

The contribution of this research lies in the development of a hybrid module that integrates print and AR *VisioBody* as an alternative to virtual laboratories, reinforcing the theories of *multimedia learning* and *cognitive load*, while providing a practical solution to the limitations of anatomical resources in higher education and presenting interactive learning innovations that are in line with the characteristics of Generation Z.

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