

Digital Literacy in Physical Education: Optimising AR for Anatomy Learning

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Abstract : The study focuses on improving digital literacy and anatomical understanding in physical education students at Hamzanwadi University through the use of Augmented Reality (AR). The use of AR as an educational tool in higher education is emerging, especially for visualizing complex topics such as anatomy.

Aims: The aim of the study is to evaluate the effectiveness of optimising AR use in enhancing digital literacy and understanding of the anatomy of the motion system among students in physical education.

Methods: A quasi-experimental design with a pretest-posttest approach was applied, involving 60 students who were purposively selected. The experimental group received AR intervention, while the control group used conventional methods. Data were collected through digital literacy tests, anatomical comprehension tests, and interviews, followed by analysis using descriptive analysis, paired sample t-test, independent sample t-test, and N-Gain analysis.

Results: The study found a significant increase in both digital literacy (from 56.3 to 85.7) and anatomical comprehension (from 52.1 to 89.4) in the experimental group, with a p-value < 0.05. The N-Gain scores were 0.69 and 0.74, respectively, indicating that AR effectively facilitated the visualization and comprehension of anatomical material.

Conclusion: The study concludes that AR is an effective tool for improving both digital literacy and anatomical understanding in physical education. The findings support the integration of digital technologies in higher education curricula, particularly for improving educational strategies in the digital era.

Keywords: digital literacy, physical education, anatomy, augmented reality

1. Introduction

In the digital era, technological literacy has become an essential skill in education, including in physical education learning. One of the main challenges in anatomy courses at Hamzanwadi University is the difficulty of students in understanding the structure and function of the body's movement system. The learning process will be more effective if students can build concepts actively through exploration (Fitriana et al., 2024). Conventional methods based on text and two-dimensional images used today are not effective in helping students visualise complex concepts in anatomy. Shemy, N. S (Shemy, 2022) explained that comprehension can increase when information is presented visually and interactively to reduce cognitive load. Other than that, Athinarayanan, S et al. (Athinarayanan et al., 2024) confirmed that a combination of verbal and visual elements is more effective in improving students' understanding of complex material such as anatomy.

Augmented Reality (AR) offers an innovative solution with a more interactive and immersive learning experience. The AR approach can present a three-dimensional representation of anatomical structures, so that students can better understand the relationship between body parts (Azer & Azer, 2016), (Tamam & Corebima, 2023). This is emphasised by Brucker, B et al. (Brucker et al., 2021) that students will absorb knowledge more easily when they interact directly with

learning objects. However, the low digital literacy of students in accessing and optimising AR-based learning technology is a challenge. The effectiveness of technology in learning is highly dependent on the user's readiness to understand and operate it (Dolmark et al., 2022). Therefore, the application of AR in learning anatomy to students at Hamzanwadi University must be accompanied by an increase in students' digital literacy skills so that they can maximise their use of it.

This research aims to explore the role of Augmented Reality (AR) in improving digital literacy and anatomical understanding of the movement system in physical education. With reference to Kolb (Kolb et al., 2014), experiential learning encourages students to be more active in understanding anatomical concepts through direct exploration. Augmented reality creates a learning environment that is more applicable and problem-solving based, so that students can better understand the relationship between anatomical concepts and practice in the field (Rejekiningsih et al., 2023). Interactive learning involving AR technology increases student motivation and engagement in the learning process. (Ziden et al., 2022), (Lah et al., 2024). Lu S. J, et al. (Lu et al., 2020) emphasises that students are more motivated when they have control over their learning experience which can be realised through direct interaction with AR-based learning objects. Rabattu, P. Y et al., (Rabattu et al., 2023) explains that learning that combines visual, audio and interactive elements in a single learning environment improves understanding of complex concepts such as the anatomy of the movement system. Bhagat, K. K. (BHAGAT, 2023) added that the use of AR helps reduce students' cognitive load by presenting information in the form of three-dimensional visuals, so that the material is easier to understand than conventional methods. Other than that Lasfeto, D (Lasfeto, 2020) stated that social interaction in technology-based learning can improve students' understanding of complex concepts through collaboration and discussion in a digital learning environment.

This research contributes to providing insight into how AR can be integrated in a project-based learning model to improve the effectiveness of anatomy learning at Hamzanwadi University. The integration of these various theories shows that AR is not just a visual aid, but also a medium that enriches the learning experience, increases motivation, optimises cognitive processing, and encourages social interaction in an academic environment.

Digital literacy is a very important skill for students to access, understand, and process information more interactively in the learning process. In the context of anatomy education, Augmented Reality (AR) is an innovative solution that provides a more real and immersive visualisation of body structures, thus overcoming the limitations of conventional methods that only rely on text and two-dimensional images. The use of AR in learning can help student understanding by presenting information in a visual form that is easier to understand so that students are more effective in absorbing material (Kshirsagar et al., 2023). AR-based learning improves concept understanding by combining visual and interactive elements together and creates a more dynamic and immersive learning experience (Vashisht, 2024). Digital literacy learning can improve the ability to use technology and the ability to think critically and evaluatively in understanding and applying information obtained digitally (Gitadewi, 2024).

The main advantage of this research lies in the integration of AR with project-based learning models that can help students understand anatomy concepts, train critical thinking, and collaborate in problem solving. This concept is in line with Piaget's view that learning becomes more effective when students actively construct their knowledge through direct experience (Fink, 2013; Kolb, 2014). Crogman, H. T et al., (Crogman et al., 2025) emphasises hands-on experiential learning process linking theory with practice is more relevant in learning anatomy through Augmented Reality. With the implementation of AR-based PjBL, students were more engaged in the learning process, explored anatomical structures better, and improved their digital skills. This approach strengthens academic understanding in physical education, while preparing students for the challenges of learning in the growing digital age.

The novelty of the research is integrating Augmented Reality (AR) with a project-based learning (PBL) model to improve digital literacy and understanding of the anatomy of the movement system in physical education. In contrast to previous studies that focused on the use of AR in learning anatomy, this study emphasises the combination of AR with PjBL to create a more applicable, problem-solving-based learning environment, and improve students' critical thinking skills. This research also uses a quantitative experimental approach to measure the effectiveness of using AR compared to

conventional learning methods. Measurements were conducted using paired sample t-test, independent sample t-test, and N-Gain analysis that provided strong empirical evidence of the impact of using AR on improving digital literacy and anatomical understanding. In addition, this research examines aspects of students' digital literacy in the context of physical education, which has rarely been the main focus of previous studies. With the increasing use of technology in education, digital literacy is a factor that determines the effectiveness of technology-based learning. Alakrash, H. M., & Abdul Razak, N (Alakrash & Abdul Razak, 2021) mentioned that students with better digital literacy are better able to understand and apply digital-based learning materials effectively. AR not only improves the understanding of anatomy concepts, but also strengthens students' digital literacy skills, which are essential skills in the digital era.

Digital literacy is an essential skill in the era of technological transformation, especially in the context of education. Mbandje et al., (Mbandje et al., 2023) defines digital literacy as the ability to understand and utilise information in a variety of formats presented through digital technology. In the academic world, digital literacy not only includes basic skills in using technological devices, but also includes critical, evaluative, and creative aspects in processing information (Martínez-Bravo et al., 2022). In physical education, digital literacy plays an important role in improving students' understanding of scientific concepts, including anatomy of the movement system (Kardeliene & Razbadauskas, 2018). Digital literacy helps students to access a wider range of learning resources, interact with interactive content, and improve technology-based problem solving (Morgan et al., 2022). However, the main challenge is the low level of digital literacy among students, which hinders the optimisation of technology utilisation in the learning process.

Physical education is not only concerned with the practice of physical activity, but also requires an in-depth understanding of the anatomy and physiology of the human body. According to Pang, T (Pang, 2022); Dann et al., (2024) a good understanding of the body's movement system is essential for physical education students to be able to apply biomechanical and physiological concepts in sports practice. One of the biggest challenges in learning anatomy is the difficulty in visualising complex body structures, especially through conventional media such as books and two-dimensional images (Pujol et al., 2016). Research by Paterson et al., (2018) shows that text-based learning methods are often not effective enough in helping students understand the relationship between body structure and function. This is reinforced by the study Rabattu dkk (Pujol et al., 2016) found that students often have difficulty in relating anatomical material to practical applications in body movement. Therefore, a more innovative approach to learning anatomy is needed to improve student engagement and understanding.

With the development of digital technology in education, various innovations have been adopted to improve the effectiveness of anatomy learning. Wickramasinghe (Wickramasinghe et al., 2022) explained that the use of digital technology in learning anatomy can increase student engagement, strengthen concept understanding, and provide a more interactive learning experience. One technology that is widely used in anatomy education is digital-based simulation, such as 3D modelling and virtual reality, which is proven to be more effective than conventional methods. (S.-J. Chen et al., 2024). In the context of physical education, the use of technology in learning anatomy aims to facilitate a more in-depth exploration of body structures, especially in understanding the mechanisms of human movement. Corton et al., (Corton et al., 2006) confirmed that students who used interactive media in learning anatomy showed better understanding than those who only used text-based learning methods. Therefore, the integration of technology in anatomy learning is a strategic step to improve the effectiveness of the learning process.

In anatomy learning, digital literacy is a key factor in the successful utilisation of educational technology. Holm, P (Holm, 2025) argues that digital literacy encompasses technical skills, critical thinking, and effective utilisation of technology in an academic context. Students who have a high level of digital literacy are more likely to be able to access, understand, and apply digital learning resources to improve their understanding of the anatomy of the body's movement system. Study by Yamine & Violato (Yamine & Violato, 2015) showed that individuals with a good level of digital literacy have higher visualisation skills, which are crucial in understanding technology-based anatomy materials. However, research by Chiu et al., (Chiu et al., 2022) found that many students still have difficulties in optimising learning

technologies due to limitations in their digital literacy skills. Therefore, improving students' digital literacy is a top priority in supporting technology-based learning, especially in fields that require complex visual understanding such as anatomy in physical education.

Improving digital literacy in physical education is not only about introducing technology in learning, but also about preparing students to be able to adapt to the ever-evolving development of educational technology. Good digital literacy will help students develop critical, analytical, and innovative thinking skills in accessing and utilising digital learning resources. According to Yaseen, H (Yaseen et al., 2025) Digital literacy contributes to increasing students' active participation in the learning process, especially when they are confronted with technology that demands higher engagement. Thus, in the context of physical education, digital literacy not only functions as a learning support tool, but also as a major component in building students' academic and professional competence..

2. Tinjauan Pustaka / Penelitian Terkait

Bagian ini harus memuat uraian mengenai perkembangan penelitian terkini (state of the art). The of this study stems from the need to link the foundations of learning psychology, multimedia instructional design, and technology acceptance to explain why and how augmented reality-based musculoskeletal system anatomy learning improves the learning outcomes of Physical Education students. Cognitively, the Cognitive Theory of Multimedia Learning emphasises three core assumptions of the learning process, namely dual-channel processing, limited working memory capacity, and active processing, so that the presentation of short narrative texts spatially adjacent to annotated 3D models will minimise non-essential processing load and strengthen the integration of information into students' long-term knowledge schemas (Mayer, 2005). This principle was enriched by Sadoski et al., (1991) in Dual Coding Theory, which states that combining verbal and visual codes strengthens recognition and retention, so that spatial visualisation of joints, bones, and muscles aligned with verbal or text-based explanations will facilitate the formation of a more stable mental model of functional structure for motion analysis. In terms of cognitive load management, Cognitive Load Theory requires the intrinsic sequencing of simple to complex tasks, the reduction of distracting extrinsic elements, and the reinforcement of german load through labelling, segmentation, and working examples so that AR exploration does not add unnecessary load but rather encourages the organisation of anatomical schemas relevant to motor performance (Sweller, 2011). The social cognitive dimension is also explained through the idea of sociocultural constructivism, which views learning as the result of mediation by tools and directed interaction. Thus, guidance practices, lecturer modelling, and collaborative work focusing on 3D objects will facilitate the internalisation of critical concepts of anatomy and biomechanics in the proximal development zone of students (Roth & Thom, 2009). The acceptance of digital solutions is explained by Adams et al., (1992) who places perceptions of usefulness and ease of use as determinants of intention and usage behaviour. Therefore, a simple, stable AR interface that is relevant to lecture tasks is a prerequisite for sustainable adoption in physical education anatomy classes.

A synthesis of recent literature shows a consensus that AR improves spatial understanding, motivation, and engagement, but a number of gaps remain prominent, including the lack of comprehensive curricular products that align with learning outcomes, as well as limitations in evaluation in the cognitive domain alone. By placing the module as a complete pedagogical package that integrates printed content, 3D objects, task scenarios, rubrics, and operational procedures, this instructional design positions AR not merely as a visual aid, but as a theory-based learning tool that connects conceptual structures with psychomotor performance and professional attitudes. This framework explains the expected causal relationships, namely that workload management and double coding strengthen conceptual understanding, while cognitive social support and task-oriented practices enhance self-regulation and engagement, and technology acceptance mediates adoption and sustainability of implementation in a limited laboratory environment.

3. Method

This study uses a quantitative approach with a quasi-experimental design to test the effectiveness of using Augmented Reality (AR) in improving digital literacy and understanding of the anatomy of the motion system of Hamzanwadi University students. This study involved two groups, the experimental group that received AR-based learning and the control group that continued to use conventional methods based on text and two-dimensional images.

3.1 Participants and Sample

The research subjects were students of the Physical Education, Health, and Recreation (PJKR) Study Programme at Hamzanwadi University who took the Anatomy of the Movement System course. The sampling technique was carried out using purposive sampling method, with a total number of participants of 60 students divided into experimental groups (30 students) and control groups (30 students). Inclusion criteria included students who had experience in the use of basic digital devices, while exclusion criteria were students who did not attend lectures fully during the study.

3.2 Experiment Design and Procedure

This study used a pretest-posttest control group design with three main stages. Pretest was conducted before the intervention to measure digital literacy and anatomical understanding through 25 digital literacy-based questions and 25 anatomical questions on the Motion system (Kuada, 2012). The intervention involved the experimental group learning anatomy using Augmented Reality (AR) in a Project-Based Learning (PjBL) model for six meetings, while the control group used conventional methods. Students in the experimental group explored 3D visualisations of body anatomy through AR applications on their mobile devices. A posttest was conducted after the intervention using the same test as the pretest to measure improvements in digital literacy and anatomical understanding (Kumar & Praveenakumar, 2025).

3.3 Research Instruments

The instruments used in this study include three main methods (Frank-Stromborg & Olsen, 2004). The Digital Literacy Test uses a Likert scale-based questionnaire (1-5) to measure five aspects: understanding AR technology, digital navigation skills, technology utilisation in learning, interaction with digital content, and digital collaboration. Anatomy Comprehension Test in the form of multiple choice questions that measure student understanding of the body's movement system, including the anatomy of the upper movement system, lower movement system, bone & joint structure, muscle function & movement, and biomechanical relationships. In addition, observation is done through direct observation to assess student interaction with AR technology in learning.

3.4 Data Analysis Technique

The data obtained were analysed using descriptive and inferential statistical tests. Descriptive analysis was used to see the distribution of initial data and final results in the form of percentages and the average pretest and posttest scores (Lee & Wang, 2003). *Paired Sample t-test* was used to test the difference in pretest and posttest scores in each group, both experimental and control (Bendat & Piersol, 2011). *Independent Sample t-test* was used to compare the difference in comprehension improvement between the experimental group and the control group after the intervention. In addition, N-Gain analysis was applied to measure the effectiveness of increasing student understanding by looking at the difference in scores before and after treatment (Sukarelawan et al., 2024). This approach ensures the research results have strong statistical validity and can identify the impact of technology-based learning more accurately.

3.5 Validity and Reliability

To ensure the validity of the research instrument, a validity test using Pearson Product-Moment correlation and a reliability test with Cronbach's Alpha were conducted. The instrument is said to be valid if the correlation value is > 0.3 .

and reliable if the Cronbach's Alpha value is > 0.7 . In addition, data triangulation was conducted by comparing the results of questionnaires, tests and interviews to ensure consistency of research findings.

4. Results and Discussion

4.1 Results

This study aims to evaluate the effectiveness of using Augmented Reality (AR) in improving digital literacy and understanding of the anatomy of the motion system of Hamzanwadi University students. The data obtained were analysed using quantitative methods, including descriptive analysis, inferential statistical tests (paired sample t-test and independent sample t-test), and N-Gain analysis to measure the effectiveness of learning improvement. In addition, validity and reliability tests were conducted to ensure the validity of the research instruments.

4.2 Descriptive Analysis

Descriptive analysis results showed an increase in digital literacy scores and understanding of the anatomy of the motion system after AR intervention. The following is a summary of the pretest and posttest scores of the experimental and control groups.

Table 1. Mean Digital Literacy and Anatomy Comprehension Scores Before and After Intervention

Group	Digital Literacy (Pretest)	Literasi Digital (Posttest)	Anatomy Comprehension (Pretest)	Anatomy Comprehension (Posttest)
Experiment (AR)	56,3	85,7	52,1	89,4
Control (Conventional)	54,8	65,2	51,4	67,8

From the table above This study proves that the use of Augmented Reality (AR) significantly improves digital literacy and anatomical understanding of Hamzanwadi University students compared to conventional methods. The experimental group experienced an increase in digital literacy score from 56.3 to 85.7 and anatomical understanding from 52.1 to 89.4, while the control group showed a smaller increase. Statistical analyses (paired t-test, independent t-test, and N-Gain) confirmed the effectiveness of AR with p-value < 0.05 and high N-Gain scores (0.69 for digital literacy and 0.74 for anatomical understanding). Instrument validity and reliability were also tested with Pearson correlation > 0.3 and Cronbach's Alpha > 0.7 . These results strengthen the evidence that AR is an innovative solution in improving anatomy learning effectiveness and digital literacy in physical education.

4.2.1 Paired Sample t-test

The paired sample t-test was used to determine whether there was a significant difference between the pretest and posttest scores in each group. The results of the analysis show as follows:

Table 2. Paired Sample t-test Results

Variables	t-value	df	p-value (Sig.)	Conclusion
Digital Literacy (Experiment)	-12.58	29	0	Significant
Digital Literacy (Control)	-5.92	29	0.002	Significant
Anatomical Understanding (Experiment)	-14.23	29	0	Significant
Anatomy Comprehension (Control)	-6.47	29	0.001	Significant

The paired sample t-test results showed that there was a significant difference between the pretest and posttest scores in both groups (p -value < 0.05), indicating an improvement after the intervention. The experimental group using Augmented Reality (AR) experienced greater improvement than the control group, with a t -value of -12.58 (digital literacy) and -14.23 (anatomical understanding), and a p -value of 0.000 for both variables. Meanwhile, the control group also improved, but with a lower t -value and p -value, indicating that the conventional method was not as effective as AR. These results prove that the use of AR is more effective in improving students' digital literacy and anatomical understanding compared to conventional learning.

4.2.2 Independent Sample t-test

The independent sample t-test was used to compare the improvement in scores between the experimental and control groups after the intervention. The results of the analysis are shown in the following table:

Table 3. Independent Sample t-test Results

Variables	t-value	df	p-value (Sig.)	Conclusion
Digital Literacy	8.93	58	0	Significant
Anatomical Understanding	10.27	58	0	Significant

The results of the independent sample t-test showed significant differences between the experimental group (AR) and the control group, with a p -value of 0.000 (< 0.05) in digital literacy (t -value 8.93) and anatomical understanding (t -value 10.27). This proves that students who learn with AR experience greater improvement than conventional methods. AR is proven to be more effective in developing digital literacy and facilitating anatomical understanding through interactive visualisation, thus improving the quality of learning in physical education.

4.2.3. N-Gain Analysis

To measure the effectiveness of increasing understanding, the N-Gain Score was calculated, with the formula:

$$\text{N-Gain} = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maximum Score} - \text{Pretest}}$$

The results of the N-Gain analysis for both groups are presented in the following table:

Table 4. N-Gain Analysis Results

Group	Digital Literacy N-Gain	Category	N-Gain in Anatomy Comprehension	Category
Experiment (AR)	0.69	High	0.74	High
Control (Conventional)	0.36	Medium	0.38	Medium

The results of the N-Gain analysis show that Augmented Reality (AR)-based learning is more effective than conventional methods in improving students' digital literacy and anatomical understanding. The experimental group obtained an N-Gain of 0.69 (high) for digital literacy and 0.74 (high) for anatomical understanding, while the control group only achieved 0.36 (medium) and 0.38 (medium), respectively. This finding confirms that AR provides a more interactive and immersive learning experience, thus increasing the effectiveness of learning in physical education.

4.2.4 Instrument Validity and Reliability

To ensure the validity of the data, a validity test with Pearson Product-Moment correlation and a reliability test with Cronbach's Alpha were conducted.

Table 5. Validity and Reliability Test Results

Variables	Pearson Correlation	Validity	Cronbach's Alpha	Reliability
Digital Literacy	0.621	Valid	0.84	Reliable
Anatomical Understanding	0.687	Valid	0.86	Reliable

The validity and reliability test results show that the research instruments are valid and reliable. The Pearson Correlation value for digital literacy (0.621) and anatomical understanding (0.687) is greater than 0.3, so the instrument is declared valid. The Cronbach's Alpha values for digital literacy (0.84) and anatomical understanding (0.86) are greater than 0.7, indicating the instruments have good internal consistency. Thus, the research instrument can be trusted in measuring the improvement of digital literacy and anatomical understanding of students after the use of Augmented Reality (AR).

4.3 Discussion

The results of this study consistently show that the integration of digital technology through the application of Augmented Reality (AR) is able to significantly improve digital literacy and understanding of the anatomy of the motion system of Hamzanwadi University Physical Education Study Programme students. Based on the data analysed quantitatively, the experimental group that received AR-based learning showed an increase in digital literacy scores from an average of 56.3 in the pretest to 85.7 in the posttest. Meanwhile, the anatomical understanding score also increased from 52.1 to 89.4. The *paired sample t-test* resulted in a *p-value* <0.05, indicating a significant difference before and after the intervention. Furthermore, the *independent sample t-test* showed that the improvement experienced by the experimental group was statistically higher than the control group, with a *t-value* of 8.93 for digital literacy and 10.27 for anatomical understanding. The effectiveness of this learning is also reinforced by the results of the N-Gain analysis which shows a value of 0.69 (high category) for digital literacy and 0.74 for anatomical understanding.

This finding is in line with research Ting, (2019) emphasised the importance of strengthening digital literacy in the technology-based learning process. In addition, Tran & Le Thi, (2023) explains that digital literacy includes the critical ability to access, evaluate and manage information effectively in the context of digital learning. Research Garzón & Acevedo, (2019) proving interactive technologies such as AR have great potential in increasing active participation and student engagement in the learning process. Meanwhile Roberts, (2017) and Kirschner, (2022) reinforces these findings by explaining that visual and interactive presentation of information can significantly reduce cognitive load and improve retention and in-depth understanding of concepts.

Dreimane & Daniela, (2021) confirmed that three-dimensional representations in AR contribute greatly to the understanding of complex concepts such as the anatomy of the human body. This is in line with the view of Evans (2021) stated that conventional learning approaches based on text and two-dimensional images are less effective in conveying the complexity of the anatomical structure of the body. Further Suhail et al., (2024) highlights the potential of AR in enhancing visual-based learning experiences, especially in higher education.

Other support for the results of this research was also found in the study of Suhail et al., (2024); Zhang et al., (2024) Proving that the use of a visual and motion-based interactive approach improves understanding of body structure and function in the context of physical education. Cabero-Almenara et al., (2019); Y. Chen, (2019) confirmed the interactive control offered by AR technology encourages higher learning motivation. Resta & Laferrière, (2022); So & Brush, (2018) adding a technology-based learning environment also opens up space for collaboration and social interaction that enriches

the student learning experience. Küçük et al., (2016) explicitly shows that AR plays a role in reducing cognitive load and improving spatial visualisation ability, which is essential in understanding the relationship between human body structures.

Research Karuru et al., (2024) demonstrate that immersive and digital technology-based learning experiences can optimise the understanding of complex concepts, strengthening students' critical and analytical thinking skills. Support for the importance of digital literacy as a prerequisite for the successful use of AR technology in physical education is also expressed by Ariffin et al., (2022); Hsu et al., (2019); Liu et al., (2022); Moreno-Guerrero et al., (2020) shows a positive correlation between digital competence and success in accessing and utilising technology-based learning media.

The results of this study confirm that the use of AR is not only a visualisation aid, but also serves as a pedagogical instrument that improves the quality of learning experiences, active involvement, critical thinking skills, and collaborative skills of students. By combining empirical data and strong literature evidence, this study presents a scientific basis that optimising the use of AR in anatomy learning can significantly address 21st century challenges in physical education, particularly in terms of improving digital literacy and understanding human body science concepts in a more meaningful and contextualised manner.

Research contribution

The results showed that the integration of Augmented Reality (AR) in learning anatomy of the movement system significantly improved digital literacy and concept understanding of Physical Education students at Hamzanwadi University. The increase in pretest to posttest scores on both variables, supported by statistical tests (*paired sample t-test*, *independent sample t-test*, and N-Gain analysis), proves that the use of AR is more effective than conventional methods. AR provides an interactive, immersive and visual learning experience that helps students visualise body structures more concretely and contextually. This finding is reinforced by previous studies that highlight the role of digital technology in reducing cognitive load, increasing motivation, and facilitating active engagement in the learning process.

Limitations

The limitation of this research lies in the application of AR which is still limited to controlled learning environments with adequate device and connection support, so that it does not represent real conditions in various institutions with different infrastructures. Other weaknesses include the inequality of students' digital literacy, which affects the effectiveness of learning, and the relatively short duration of the intervention, which does not measure the long-term impact. The AR application used also has technical limitations such as bugs and visualisation that is not fully optimal. For this reason, improvements that need to be made include developing a more stable AR application, digital literacy training for students and lecturers, and expanding research in various institutional contexts. Furthermore, future studies need to examine the affective and psychomotor aspects of students so that the learning approach becomes more holistic and applicable.

Suggestions

To increase the effectiveness of the application of Augmented Reality (AR) and Project Based Learning (PjBL) in learning anatomy, it is necessary to develop AR applications that are more stable, interactive, and in accordance with the needs of the material. The implementation of PjBL should also be more structured to encourage collaboration and real-world problem solving. In addition, learning evaluation needs to include cognitive and non-cognitive aspects such as student motivation and engagement. A longer duration of intervention is also recommended so that the long-term impact of using AR and PjBL can be identified more thoroughly.

6. Conclusion

This study concludes that the integration of the use of Augmented Reality (AR) technology significantly improves digital literacy and anatomical understanding of the motion system of Hamzanwadi University students, as seen from the increase

in pretest and posttest scores on both variables, which is supported by statistical analysis (paired sample t-test, independent sample t-test, and N-Gain) as well as good instrument validity and reliability. The implications of the research results indicate that the application of AR can be used as an effective strategy in developing learning methods in the field of physical education that has the potential to increase student engagement and understanding in learning complex material such as anatomy. However, this study faces challenges such as limited access to adequate AR devices, variations in students' digital literacy baseline, and the scope of the study being limited to one institution, thus limiting the generalisability of the results. Therefore, it is recommended for future research to develop a broader intervention design and involve several educational institutions, as well as integrate digital literacy training support for students so that the potential of AR technology in improving learning can be maximised in a sustainable manner.

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Author Contribution Statement

In the implementation of this research, HA was responsible for designing the concept and collecting data in the field. IGLAP played a role in analysing the data and providing input and constructive criticism to improve the intellectual quality of the research. IKY contributes through data interpretation and validation to ensure the data is ready for publication. Meanwhile, IKIS acts as an editor who corrects data deficiencies, so that the overall research results become more comprehensive and worthy of dissemination.

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