International Journal of Health and Medicine

E-ISSN: 3047-793X
P-ISSN: 3047-7948

Research Article

Integration of Augmented Reality in Anatomy Learning : Innovation in Health Education

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Abstract: The development of digital technology brings great opportunities in the world of education, especially in the health sector. Augmented Reality (AR) is one of the technological innovations that is able to integrate virtual objects into the real environment in real-time, providing a more immersive and interactive learning experience. This article aims to explore the integration of AR in anatomy learning based on literature studies from international journals. Using a qualitative approach based on literature studies, this study examines various findings from foreign scientific journals regarding the effectiveness, challenges, and potential of using AR in anatomy education. The results of the study show that AR is able to improve students' visual understanding, learning engagement, and information retention. However, there are also challenges in terms of development costs, technology access, and teacher readiness. AR has great potential as a medium for anatomy learning in the digital era, but its implementation requires adequate infrastructure and training support.

Keywords: Augmented, Reality, Health, Education, Anatomy

1. Introduction

Health education is one of the fields of study that requires a deep understanding of the structure and function of the human body. In this case, anatomy is the main foundation for prospective health workers, such as doctors, nurses, and physiotherapists. A good mastery of anatomy is key to understanding pathology, clinical procedures, and effective medical communication. However, the complexity of the human body with its various interconnected systems and structures often poses a challenge in the learning process. Traditionally, anatomy learning methods rely on textbooks, two-dimensional diagrams, and three-dimensional anatomical models made of plastic or synthetic materials. Although these methods have been used for years and have proven effective in some aspects, many students have difficulty in connecting theoretical material with real visualizations of the human body. Limited access to cadavers as the main teaching material is also an obstacle, especially in educational institutions with limited facilities.(Gomathi, 2024).

In responding to these challenges, technology has begun to play an important role in the world of education, including in anatomy education. One of the innovations that is developing rapidly is Augmented Reality (AR) technology. AR is a technology that allows digital objects to be displayed in real-time and interact directly with the real world through devices such as smartphones, tablets, or smart glasses. In the context of education, AR provides a more immersive and contextual learning experience. The use of AR in anatomy learning allows students to see the structure of the human body in three dimensions, manipulate organ positions, and observe interactions between body systems on a more accurate scale. With this approach, material that was previously difficult to understand abstractly can be visualized in a more concrete way. Not only does it increase the appeal of learning, the use of AR also stimulates active student involvement in the learning process(Zafar & Farooq, 2021).

Received: March, 11th 2025
Revised: March, 25th 2025
Accepted: April, 15th 2025
Published: April, 17th 2025
Curr. Ver.: April, 17th 2025

Various international studies have shown that the integration of AR in anatomy education can improve students' conceptual understanding, information retention, and learning interest. Students are not only passive recipients of information, but also active participants who explore the material at their own pace and learning style. This is in line with the principles of modern learning that emphasize personalization and meaningful learning experiences. However, the application of AR technology in anatomy education is not free from various challenges. Several studies show that the readiness of technological infrastructure, digital skills of educators, and the cost of developing and maintaining applications are the main inhibiting factors. In addition, further research is still needed regarding the long-term effectiveness of AR on students' academic achievement and its impact on professional competence in the field. (Pezzino et al., 2025).

2. Method

This study adopts a qualitative approach with a literature review method that aims to collect, review, and synthesize findings from various scientific sources regarding the use of Augmented Reality (AR) technology in anatomy education. The main focus of this study is to understand how AR is integrated into the learning process, the extent to which it is effective in improving student understanding, and the challenges faced in its implementation. The data collection process was carried out systematically by searching international journals published between 2015 and 2024. The main sources come from highly reputable databases such as Scopus, PubMed, ScienceDirect, and Google Scholar, to ensure that the literature reviewed has strong academic credibility and is relevant to the research context. In the search process, specific keywords were used such as "Augmented Reality in Anatomy Education", "AR in Medical Training", and "Innovative Learning Technologies in Health Education". Inclusion criteria in literature selection include peer-reviewed articles, in English, and discussing the topic of AR integration in anatomy education from aspects of technology design, implementation strategies in educational environments, to learning evaluation. Articles that were only theoretical without real implementation studies were excluded from the analysis. After the selection stage, the data obtained were analyzed thematically by highlighting the general patterns that emerged, such as the effectiveness of AR in improving learning outcomes, user responses (students and lecturers), technical constraints, and recommendations from researchers. This thematic analysis aims to produce an in-depth and comprehensive synthesis of information, so that it can provide a complete picture of the role and potential of AR technology in shaping the future of more interactive and adaptive anatomy education. (Khader et al., 2024).

Table 1

No	Year	Title	Research Focus	Key Findings
1	Alzahrani, NM	2020	Augmented Reality: A Systematic Review of Its Benefits and Challenges in E-learning Contexts	A systematic review of AR in e-learning AR increases engagement, but challenges like infrastructure and training remain large
2	Aswandi, N.	2025	Sector Transformation through AR: Benefits, Challenges and Strategic Future	Benefits of AR in various sectors including Education AR supports digital transformation, but high costs and limited access are obstacles
3	Gomathi, B.	2024	AR and Nursing Care Improvement	Improving nursing care efficiency with AR. AR accelerates clinical decision making and patient outcomes.
4	Khader, A. et al.	2024	Mediverse Beyond Boundaries	Integration of AR and VR in medical education. The combination of AR and VR supports inclusive and adaptive learning.
5	Koumpouros, Y.	2024	Prospects of AR in Education	The potential of AR at various levels of education. AR strengthens students' understanding of

				complex concepts and spatial abilities.
6	Moro	2021	HoloLens and Mobile AR in Medical Education	Controlled trial on the effectiveness of AR. AR showed significant improvements in retention and learning outcomes.
7	Neri, I. et al.	2024	AEducAR 2.0 Study	Interdisciplinary study of the use of AR in anatomy education. AR facilitates the process of learning anatomy visually and practically.
8	Ni, S. & Listiani, I.	2024	AR and TaRL in Anatomy Learning	Integration of AR and TaRL approaches This integration has been proven to improve the learning outcomes of grade VI students.
9	Pernando, Y. & Kh, M.	2023	AR as a Learning Media for Skeletal Systems	Implementation of AR on skeletal system material. AR increases interest and understanding of basic anatomical concepts.
10	Pezzino, S. et al.	2025	Intelligent Tools in Digital Anatomy Teaching	Bibliometric exploration of digital anatomy teaching. Research trends support AR adoption for anatomy learning efficiency.
11	Resti, N. & Palupy, RT	2024	AR Innovation in Digestive System Material	AR for junior high school science materials. AR makes learning more interactive and easier for students to understand
12	Simon, PD et al.	2025	AR in Environmental Education	Review of the use of AR in environmental education Although not anatomical in focus, AR has been shown to improve understanding of complex scientific topics.
13	Singh, S. et al.	2022	The Impact of AR on Education	Bibliometric exploration of AR in Education. AR is seen as a revolutionary tool in 21st century pedagogy.
14	Tene, T. et al.	2024	AR in Medical Education: An Umbrella Review	A broad review of AR studies in medical education. AR effectively supports anatomy, clinical, and medical procedure simulation education.
15	Zafar, A. & Farooq, MS	2021	AR in Healthcare Education for Human Anatomy	The use of AR in Health anatomy education. AR has been shown to improve mastery of spatial concepts of human anatomy.

3. Result

Based on the 15 journal articles reviewed, several main themes were found:

Improved Visual and Spatial Understanding

One of the most consistent key findings across the 15 journal articles analyzed was that the use of Augmented Reality (AR) significantly improved students' visual and spatial understanding of human anatomical structures. Traditional anatomy learning relies heavily on two-dimensional media such as textbook images or static models that are limited in showing the dynamic relationships between organs. AR is an innovative solution that allows for interactive and realistic representation of body structures in three dimensions (3D). Students can view, rotate, zoom in, and explore the entire structure of body organs, which directly helps build a more accurate spatial understanding. Several studies have shown that AR models allow users to observe human anatomy from various angles, even down to microstructures

such as blood vessels or the structure of the central nervous system. Interaction with these 3D objects creates a much more immersive learning experience than simply reading descriptions or viewing two-dimensional images. Students who learned anatomy with the help of AR showed significant improvements in identifying body structures compared to groups using conventional methods. They were able to more quickly understand the location, size, and relationships between body parts.(Tene et al., 2024).

AR's ability to display animations or simulations is also an added value in helping dynamic understanding. For example, AR can show muscle movements as the body moves, blood flow through the cardiovascular system, or how the nervous system sends signals to different parts of the body. Visualizing these processes not only helps understand the "what" and "where", but also "how" a body part functions, providing a holistic understanding that is very important in health education. This directly supports the clinical skills that students will need in the world of work later. Not only cognitive understanding, AR technology also helps form a better mental mapping of body structures. Students who learn with the help of AR tend to have stronger visual memory because their learning experience involves direct interaction with the objects being studied. Students with a visual learning style showed a more significant increase in performance when using AR media in anatomy studies compared to conventional learning methods. This shows that AR can be an effective tool to accommodate various learning styles in heterogeneous classes.(Moro, 2021).

In addition, AR can bridge the gap between theory and practice in anatomy learning. In certain conditions, such as limited access to corpses for dissection practice or limited laboratory equipment, AR is a very helpful alternative. Students can still gain an in-depth understanding of the structure of the human body without having to rely on physical facilities. This advantage makes AR a relevant and sustainable learning tool, especially in educational institutions with limited resources or in distance learning situations. Overall, the results of the 15 peer-reviewed journals showed that AR plays a major role in improving students' visual and spatial understanding in anatomy learning. By utilizing this technology, the learning process becomes more contextual, intuitive, and enjoyable. Although not a total replacement for traditional learning methods, AR has proven to be a very effective complement to optimize students' understanding of the complex structure of the human body.(Koumpouros, 2024).

Increased Engagement and Motivation

One of the main advantages of using Augmented Reality (AR) in anatomy learning is its ability to increase student engagement and motivation. Many studies have shown that AR successfully creates a more interactive and engaging learning experience compared to conventional learning methods. Students who use AR tend to feel more engaged and actively participate in the learning process. This is especially important in the context of health education, where understanding and practical skills are essential. More interactive and engaging anatomy learning can reduce the boredom that students often experience when studying highly technical and complex material. Several studies have also highlighted that AR not only increases students' attention during learning, but also strengthens their engagement in class discussions and group activities. This technology makes students more active in exploring the material and more ready to contribute to discussions or group assignments. Students who use AR to learn anatomy are reported to feel more engaged in lecture sessions because they can directly interact with real and immersive human body models. This interaction encourages them to ask questions, discuss topics, and hone their problem-solving skills directly.(Alzahrani, 2020).

In addition, the increased motivation caused by AR is also related to the way this technology presents material in a gamified and fun way. Many AR applications are designed with game elements that allow students to learn while having fun. The use of gamification elements such as time challenges, achievements, and learning levels gives students a sense of accomplishment that can increase their motivation to continue learning and explore further. AR-based learning experiences are not only more fun but also provide real-time feedback, which motivates students to keep trying and correcting their mistakes without feeling embarrassed or frustrated. The interactive elements and feedback provided by AR strengthen

students' engagement in the learning process. AR provides a more personalized and adaptive experience, meaning that each student can learn at their own pace and style. The variety of features in AR applications, such as the ability to change perspectives or access more information by simply clicking on an object, allows students to tailor their experience to their individual needs. This increases their sense of control over the learning process, which is a key factor in maintaining motivation.(Singh et al., 2022).

In addition, this interactive learning experience also provides students with the opportunity to experience the practical application of the anatomical knowledge they have learned. For example, students can use AR to simulate medical procedures or explore biological processes that occur in the human body. Thus, the learning process is not only about memorizing the names of organs or body structures, but also connecting theory with real practice. The ability to see and understand human anatomy in a more practical context makes students feel more prepared to face challenges in the medical world and increases their motivation to continue studying the field. This high motivation is also reflected in the increase in student participation in AR-based exams or evaluations. For example, some AR applications can be used to test students' understanding directly through simulations. Students are asked to recognize and identify various body structures in 3D models, or to perform certain actions based on their knowledge of anatomy. Students who undergo AR-based evaluations show a higher level of confidence in facing exams because they have practiced in simulations that are similar to real situations.(Neri et al., 2024).

Learning Flexibility

Flexibility is one of the important aspects gained from the use of Augmented Reality (AR) in anatomy learning, which was identified in this study as one of the main advantages. One of the great attractions of AR is its ability to allow students to learn outside the classroom independently using mobile devices such as smartphones or tablets. Students are no longer limited to a certain time and place to access learning materials. They can use AR applications to review lessons, do further exploration, or complete individual assignments anytime and anywhere, which gives them the freedom to set the pace of learning according to their personal needs. In the context of higher education, especially in the health sector, this flexibility is very helpful for students who have busy schedules or limited time to attend face-to-face lectures. The use of AR allows students to study anatomy independently at home or in the study room, without having to rely on limited practical sessions or access to the laboratory. This opens up opportunities for students to delve deeper into certain topics that they find difficult or want to learn more deeply without having to wait for the opportunity in class.(Simon et al., 2025).

The use of AR also allows for a more adaptive learning experience, which is especially useful for students with different learning styles. AR provides the opportunity to tailor the material to individual needs, whether in terms of learning pace, difficulty level, or how information is delivered. For example, students who struggle with understanding anatomy can slow down their interaction with AR objects or focus on certain, more complex structures. In this sense, AR supports the personalization of learning that cannot always be achieved with traditional methods such as lectures or textbooks. Furthermore, the flexibility of learning also allows for greater access for students from different backgrounds, including those who may have limitations in terms of mobility or access to complete educational facilities. By using mobile-based AR, students who live in remote areas or far from campus can easily access learning materials. This certainly reduces the educational gap that often occurs between students from different geographic locations or socio-economic backgrounds.(Resti & Palupy, 2024).

In addition, AR's ability to provide immediate feedback during the learning process enriches the self-paced learning experience. Students can test their understanding directly through AR-based quizzes or simulations that provide real-time assessments. When students make mistakes in recognizing body structures or understanding the relationships between organs, the AR application can immediately provide clear explanations and suggestions for improvement. Thus, students can learn more efficiently and effectively without having to wait for instructions from lecturers or face-to-face teaching. With the flexibility offered by AR,

students are also given the opportunity to learn concepts that may not be possible within the constraints of time or traditional classrooms. For example, AR allows students to study anatomy in more depth through simulations of biological or pathological systems, allowing them to understand anatomical changes in a clinical or medical context. This not only enriches their knowledge but also provides them with practical skills that are essential in their medical careers. This flexibility gives students more time to explore the material in depth and allows them to learn at their own pace and at their own personal needs.(Pernando & Kh, 2023).

Implementation Challenges

Although Augmented Reality (AR) technology offers a variety of advantages in anatomy learning, its implementation in education is not without challenges. Several studies analyzed in this research identified several major barriers that hinder the widespread adoption of AR in health education, especially in the field of anatomy. The first challenge that is often mentioned is the limited hardware required to run AR applications optimally. To be able to utilize AR properly, students and educational institutions need mobile devices or AR headsets that are sophisticated enough to support interactive and immersive learning experiences. However, such devices are often expensive, and not all educational institutions have the budget to provide such equipment in sufficient quantities. In addition to hardware issues, the second challenge faced is the limitation in the development and provision of AR content that is in accordance with the educational curriculum. Creating quality AR content requires a lot of resources, both in terms of time, effort, and cost. Developing AR applications requires collaboration between technology developers, lecturers, and anatomists to ensure that the content produced is not only scientifically accurate but also relevant to learning objectives. This is often a major obstacle, especially in developing countries or in institutions with limited budgets, which cannot provide sufficient funds for the development or purchase of high-quality AR content.(Ni & Listiani, 2024).

Another significant challenge is the lack of adequate skills and training for lecturers in using AR technology. To be able to harness the full potential of AR, lecturers need to have a strong understanding of how this technology works and how to integrate it effectively into the teaching process. Unfortunately, not all lecturers have a technological background or expertise in this field. Many lecturers feel hesitant or have difficulty adapting AR-based teaching methods, because they do not have sufficient knowledge about the devices and how to implement them in the classroom. Therefore, training and professional development for lecturers is very important to ensure the success of AR implementation in learning. In addition, challenges in terms of infrastructure and connectivity are also problems in some educational institutions. In many areas, especially in developing countries, the problem of fast and stable internet access is a major obstacle in accessing cloud-based AR content or AR applications that require high internet speeds. In some areas, unstable internet connections can lead to disrupted learning experiences, which reduces the effectiveness of AR use. Educational institutions that do not have adequate technological infrastructure will struggle to make the most of AR, which of course limits the distribution and accessibility of this technology.(Gomathi, 2024).

Another aspect that needs to be considered is excessive reliance on technology. Several studies have shown that excessive use of AR in learning can cause students to rely too much on technology and not develop the basic skills needed in learning anatomy, such as the ability to remember and analyze information manually. In a study by McLoughlin et al. (2018), it was found that although AR can improve students' understanding, continuous use of technology without balancing it with traditional methods can cause students to lose important basic skills. Therefore, it is important to ensure that AR is used as a complementary tool, not as a total replacement for conventional learning methods. Another challenge is related to the aspect of evaluating and measuring the effectiveness of AR in education. Although many studies have shown the benefits of AR, evaluation of the long-term effects of using AR in learning is still limited. Several studies have shown that although students feel more interested and engaged, there is no clear consensus regarding the long-term impact of AR on knowledge retention or improving clinical skills. Research by Pimmer et al. (2021) emphasized that although AR provides a fun and interactive learning experience, more research is needed to determine

whether this technology actually improves student learning outcomes in the long term and whether it can be widely implemented in all medical curricula.(Zafar & Farooq, 2021).

4. Discussion

The use of Augmented Reality (AR) in anatomy learning has been proven to have a positive impact, especially in improving students' understanding of the complex structure of the human body. Anatomy is a branch of health science that involves an in-depth understanding of the form and function of various organs and systems in the body. Conventional methods that rely on textbooks and three-dimensional models are often unable to describe the relationship between body structures in a more interactive and realistic way. This is where AR plays an important role. AR helps students visualize organs and body systems in more detail and dynamically, which makes it easier for them to understand previously difficult-to-understand material. With three-dimensional object visualizations that appear directly in the real world, students can explore various perspectives, and gain a deeper understanding of human anatomy. Along with its ability to improve visual understanding, AR also has an impact on improving student learning outcomes. Students who use AR in anatomy learning show significant improvements in terms of material understanding and long-term information retention. This is due to the way AR provides a more interactive learning experience, where students can interact directly with three-dimensional human anatomy models. This more comprehensive and immersive learning experience encourages students to be more involved in the subject matter, which leads to improved quality of learning outcomes and deeper understanding of concepts. Therefore, AR can be considered as an effective tool to enhance learning outcomes, especially in areas that require strong spatial and visual understanding.(Pezzino et al., 2025).

While AR has many benefits in enhancing anatomy learning, a major challenge is limited access to the technology. In many developing countries, especially in remote areas or with limited infrastructure, access to the devices needed to run AR applications is often a major barrier. The sophisticated mobile devices needed to use AR applications may be beyond the reach of many educational institutions or students, which in turn limits the implementation of this technology in anatomy education. The successful use of AR in learning relies heavily on adequate technological infrastructure, such as appropriate hardware and fast internet connections. Without adequate access, the benefits that AR can provide will be severely limited, and students and instructors will not be able to harness the full potential of this technology. In addition to the issue of access to technology, another challenge that must be faced is the lack of training and understanding of the teaching staff regarding the use of AR. In many cases, lecturers or instructors who are not familiar with new technologies such as AR will find it difficult to integrate it into their teaching methods. Without adequate training, they may not be able to optimize the use of AR in the classroom or may even avoid using it altogether. Inadequate training for instructors is one of the biggest barriers to effective AR adoption. Teachers need to understand how to operate AR devices, how to integrate them with course materials, and how to use AR to support their learning objectives. Therefore, developing effective and sustainable training programs is essential to ensure that AR can be used optimally in the anatomy learning process.(Khader et al., 2024).

In addition, another equally important challenge is the cost of developing high-quality AR content. Creating interactive AR content that is in accordance with the educational curriculum requires a lot of money. Developing accurate three-dimensional anatomical models that meet scientific standards requires a lot of time and expertise. This high development cost is an obstacle for many educational institutions, especially in developing countries that have limited budgets. Therefore, it is important for technology developers and educational institutions to find more efficient solutions in creating and distributing AR content, such as developing open-source platforms or using collaborative learning models between developers and teachers to create more affordable but still high-quality content. In terms of sustainability, it is important to consider the accessibility aspect of technology in the long term. AR content designed for anatomy education must be easily accessible and integrated into various platforms used by students and teachers. This means that the development of AR technology must consider the diversity of devices used by users, such as smartphones or tablets with lower specifications. In addition, content sustainability also means ensuring that the content

created can be updated regularly to remain relevant to the latest developments in anatomy. AR development that does not pay attention to sustainability and ease of access could risk causing this technology to become just a temporary trend without having a significant impact in the long term.(Tene et al., 2024).

In order to address the challenges of accessibility and cost, an alternative solution that can be considered is the use of more affordable devices that still have the capability to run AR applications. For example, many educational institutions are starting to use smartphone-based AR applications that can be downloaded for free or at a lower cost than other high-end hardware. Such applications allow students to access learning materials anytime and anywhere, without the need for expensive hardware. Smartphone-based AR applications can provide a learning experience that is nearly equivalent to more expensive AR hardware, with the added benefits of flexibility and ease of access. The use of smartphone-based applications allows AR-based anatomy education to be more affordable and accessible to students in various regions, especially those outside of large educational centers.(Aswandi, 2025). However, although more affordable devices can help overcome cost issues, the implementation of AR in anatomy learning still requires attention to the quality of teaching. The use of AR must be well integrated into a broader teaching methodology, so that this technology is not only an aid, but also an integral part of the development of student competencies. AR should not be just a substitute for anatomical models or textbooks, but rather a means to deepen understanding through direct interaction with the objects being studied. For this reason, it is important for teachers to design learning experiences that combine AR elements with other teaching techniques, such as group discussions, practical assignments, and application-based exams, so that students do not only rely on technology but also develop critical and analytical skills in solving problems.(Koumpouros, 2024).

5. Conclusions

The integration of Augmented Reality (AR) in anatomy learning has a significant positive impact on the quality of education, especially in improving understanding of the complex structure of the human body. Based on findings from various international studies, AR allows students to learn interactively through three-dimensional visualizations that make it easier for them to understand anatomy in a more realistic and in-depth way. By using AR, concepts that are difficult to visualize through two-dimensional media, such as textbooks, can be understood more clearly, and the learning process becomes more interesting and effective. In addition, AR can also increase student engagement, thereby increasing their motivation to learn and explore topics further. However, to ensure that the implementation of AR in anatomy education can run effectively, various preparations are needed, such as the development of adequate infrastructure, training for teaching staff, and the creation of AR content that is in accordance with curriculum needs. The success of AR implementation depends on the synergy between educational institutions, technology developers, and educators to create an optimal learning experience. Therefore, further collaboration is needed to overcome challenges related to costs, training, and content development so that AR can be used sustainably and provide maximum benefits in future health learning.

6. Suggestion

Based on the results of the literature review, several suggestions that can be given to optimize the use of Augmented Reality (AR) in anatomy learning in Indonesia include the development of local AR-based content that is relevant to the national curriculum and local cultural context. This will make it easier for students to understand the material presented and make learning more connected to their experiences. In addition, it is also important to provide sufficient training and mentoring for lecturers and instructors so that they can integrate AR technology effectively into the learning process. The success of AR implementation is highly dependent on the readiness of teachers to utilize this technology properly. In addition, the next suggestion is the need for multidisciplinary collaboration between health, information technology, and multimedia design faculties. This collaboration aims to create AR media that is not only visually appealing, but also scientifically accurate and technically efficient. Further research in the local context is also needed to test the effectiveness of AR in anatomy learning settings in Indonesia. This will be a strong basis for

policy making in the development of a broader digital learning system. Finally, support from the government and educational institutions in terms of infrastructure and policies is very important to encourage AR-based learning innovation, including the provision of funding, curriculum development, and procurement of necessary devices.

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