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Implementation of Markerless Augmented Reality For Human Anatomy Education

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Augmented Reality; Markerless, Education, Human Anatomy, Interactive Learning

ABSTRACT
This research aims to develop and implement Augmented Reality (AR) technology as an interactive learning medium for introducing human body anatomy using a markerless method. The background of this research is the lack of interest and understanding among students regarding biology, particularly anatomy, which has traditionally been delivered through conventional methods such as textbooks or two-dimensional images. AR technology allows students to visualize three-dimensional models of human body parts directly in the real world, without the need for physical markers, thereby creating a more engaging, flexible, and accessible learning experience. The methods used in this research include planning stages, needs analysis, data collection through interviews and observations, application development using Unity and Vuforia SDK, and finally, implementation and evaluation. The application developed was tested at SMAN 1 Bulakamba and resulted in an increase in students' understanding and interest in learning anatomy. The evaluation results show that the majority of students stated they understood the material very well after using this AR application, with high average scores on each questionnaire indicator. Thus, the application of markerless AR technology has proven effective as an interactive visual education tool and holds great potential for implementation in biology education as well as other subjects that require complex visualizations.

INTRODUCTION

Augmented Reality (AR) technology is now increasingly common in various sectors, including education, thanks to its ability to provide creative solutions for learning (Azuma, 1997; Elmqaddem, 2019; Grubert et al., 2017; Pinto et al., 2022). AR enables the integration of the real and virtual worlds, allowing students to see digital objects displayed in a physical environment (Yusof et al., 2020). In education, AR opens up new opportunities to address various challenges faced by students, particularly in understanding difficult, abstract concepts, such as human anatomy. Traditional teaching methods are often inadequate in helping students effectively grasp complex concepts, such as using only two-dimensional images or diagrams in textbooks (Hikmandayani & Kartini, 2024).

Technological advancements have brought positive changes to education, particularly through the integration of technology into the learning process. One rapidly developing technological innovation is Augmented Reality (AR), which allows the integration of 3D visuals into the real world using digital devices, such as mobile phones or tablets, without the need for physical markers (markerless) (Abdinejad et al., 2021; Miyake et al., 2017; Rakshit et al., 2023; Raval et al., 2021; Verkhova et al., 2019). Markerless AR has the added advantage of not requiring special physical elements, such as images or code, to display virtual objects, making it more flexible and practical for application in various learning environments. At SMAN 1 Bulakamba, students often experience difficulty understanding complex biology material, particularly when studying the parts of the human body. Conventional learning methods, such as lectures and textbooks, are often unengaging and fail to present information in a way that is easy to understand. As a result, students' motivation to learn decreases. They tend to be less engaged with the material presented, primarily due to difficulty visualizing the relationships between various body organs and their functions. In this context, the application of AR technology can provide an effective solution to improve the quality and appeal of learning.

The main advantage of markerless AR in learning is its ability to display more detailed and interactive visualizations (Ikmah et al., 2023). Students can view digital objects in three dimensions, allowing them to rotate or zoom in on the objects for further study. AR also provides opportunities for students to interact with the digital objects, for example, selecting a specific body part to learn more about its function. This creates a more immersive learning experience and allows students to learn independently in a more engaging way.

In anatomy learning, the use of markerless AR is very effective because it allows for more detailed and realistic visualizations of human body parts (Nauko & Amali, 2021). Compared with traditional two-dimensional image-based methods, AR allows students to see and understand body organs in three dimensions, allowing them to better understand their structure and function. The use of AR in anatomy lessons enhances students' overall understanding and makes the learning process more engaging and enjoyable.

However, while AR offers significant potential, its implementation in schools is still hampered by limited infrastructure and costs. Many schools lack the technological devices to support AR, such as smartphones or tablets with adequate specifications. Furthermore, the cost of developing AR content presents a challenge, especially for schools with limited budgets. Nevertheless, schools that have used AR in their learning have reported a significant increase in student interest and motivation. They are more engaged and find it easier to grasp concepts previously considered difficult.

Schools that use only conventional learning methods often encounter challenges due to students' boredom with less interactive materials. Conventional learning is often passive, with students simply listening to the teacher or reading a textbook without much opportunity to interact with the material being taught. Therefore, the application of AR in anatomy lessons is considered a potential solution. With markerless AR, students can visualize body organs in detail and interactively, without the need for physical markers. This technology is more flexible, as students simply need to use their devices to scan the real-world environment without any special markers.

Previous studies have demonstrated the potential of Augmented Reality (AR) in enhancing student learning outcomes, particularly in science education. For example, Bacca et al. (2019) highlighted that AR increases motivation and engagement by enabling students to interact with immersive and contextualized learning materials. However, their study mainly focused on marker-based AR, which often requires physical cards or markers, limiting flexibility in classroom settings. Similarly, Garzón and Acevedo (2019) found that AR significantly improved conceptual understanding in biology, yet they noted challenges related to accessibility, device compatibility, and the high costs of AR implementation. These findings underscore the value of AR but also reveal gaps regarding practical application in schools with limited resources and the lack of focus on markerless AR approaches.

This research aims to apply Augmented Reality technology as an educational medium to introduce human body parts using a markerless method (Sadeghi-Niaraki & Choi, 2020). With this method, three-dimensional objects can be displayed without the need for physical markers, making visualization more accessible and flexible for students. Furthermore, the markerless method provides freedom for application developers, as it eliminates the need for physical markers or visual codes to be scanned. Instead, AR applications utilize direct object detection through the device's camera, making them more responsive and efficient (Sadeghi-Niaraki & Choi, 2020).

It is hoped that the application of the markerless method in AR can increase learning effectiveness, overcome the limitations of traditional methods, and positively impact student interest and motivation in understanding human anatomy more deeply. This technology is also expected to strengthen student engagement in the learning process, making them active participants who not only passively receive information but also interact directly with the material being studied.

Thus, this research aims to explore the potential of Augmented Reality as an educational tool to introduce human body parts using a markerless method. Using AR, it is hoped that students' learning experiences will be more interactive, immersive, and able to improve learning outcomes, particularly in understanding human anatomy (Frialdo et al., 2023). This technology is not only expected to improve the understanding of more complex concepts, but also to foster stronger student learning motivation, thereby supporting overall educational goals.

METHOD

This research used a Research and Development (R&D) approach with the Multimedia Development Life Cycle (MDLC) software development model. This model consists of six stages: (1) concept, (2) design, (3) material collection, (4) assembly, (5) testing, and (6) distribution. This approach was chosen because it aligns with the needs of designing and developing a markerless Augmented Reality (AR)-based educational application.

The research was conducted at SMAN 1 Bulakamba, Brebes Regency, Central Java. The subjects were 11th-grade students taking Biology. The location was selected based on initial findings that human anatomy learning was still dominated by conventional methods, which made students less interested and difficult to understand (Musthofa et al., 2024; Enowato et al., n.d.).

The research stages

1) Needs analysis – conducted through observations of the biology learning process, interviews with biology teachers, and questionnaires given to students regarding their anatomy learning experiences.
2) Application design – including storyboard creation, user interface (UI) design using Canva, and 3D modeling of human organs using Blender (Pratama et al., 2021).
3) Application development – conducted using Unity 3D with Vuforia SDK integration to support markerless AR features.
4) Limited testing – the application was piloted with students to determine ease of use, appeal, and learning effectiveness.
5) Evaluation and revision – the results of the pilot were analyzed to assess the application's effectiveness, followed by improvements based on student and teacher feedback.

The methods used were:

1) Observation: to observe student activities while using the application.
2) Interviews: with biology teachers to explore challenges in anatomy learning and perceptions of the use of AR.
3) Literature study: conducted by examining literature, scientific journals, and previous research related to the application of Augmented Reality in education, particularly in biology and anatomy subjects.
4) Documentation: recording and storing technical information related to the hardware and software used in developing the Augmented Reality application.
5) Data were analyzed using a quantitative descriptive approach. Questionnaire scores were calculated as percentages to determine assessment categories (very poor, poor, sufficient, good, and very good). The analysis results were used to assess the extent to which the markerless AR application improved students' understanding and interest in learning human anatomy.

RESULTS AND DISCUSSIONS

Implementation Results

This research successfully developed a markerless Augmented Reality (AR)-based learning application for human anatomy recognition. The application was built using Unity 3D and the Vuforia SDK, with 3D models of body organs (lungs, heart, liver, skin, and kidneys) designed using Blender 3D, and the interface designed using Canva.

The application was tested at SMAN 1 Bulakamba and ran well on Android devices. Students could access 3D objects without the need for physical markers, simply by pointing their smartphone cameras at a flat surface. The application's main features include: 3D visualization of human organs (rotating, zooming in, and zooming out objects); Direct interaction with objects (selecting an organ to view a functional description); and an interactive quiz module to measure student understanding after the lesson.

Questionnaire Results

To evaluate the application's effectiveness, eleventh-grade students completed a questionnaire. The questionnaire consisted of six indicators: conceptual understanding, ease of navigation, visual appeal, learning motivation, interaction, and learning effectiveness.

A summary of the questionnaire results is as follows:

1. Conceptual understanding: The majority of students (62.5%) stated they "almost understood" to "very understood."
2. Ease of navigation: More than 70% of students found the application easy to use.
3. Visual appeal: 75% of students found the 3D visualizations engaging.
4. Learning motivation: 80% of students stated they were more motivated to learn with AR.
5. Interaction with the application: Most students felt actively engaged through the interactive features.
6. Learning effectiveness: 73% of students considered the application very helpful in understanding anatomy.

Overall, the application achieved an average validation score of 43.38% in the "Good" to "Very Good" category, indicating that markerless AR is effective as an anatomy learning medium.

Analysis of Results

The test results showed that markerless AR was able to overcome the weaknesses of conventional methods. Students were able to understand anatomical concepts visually, not solely through text or 2D images. Interaction with 3D objects increased student engagement, in line with constructivist learning theory, which emphasizes hands-on experience as the key to understanding.

Furthermore, markerless technology offers greater flexibility than marker-based AR, as students do not require additional media to access content. This allows learning to take place anywhere and anytime using only a mobile device.

Discussion

The application of markerless AR technology in this study aligns with the findings of various previous studies that have proven this technology effective in improving the quality of learning. With realistic and interactive visualizations, AR technology makes it easier for students to understand complex material, especially topics that require in-depth visual understanding, such as human anatomy.

The markerless method has a key advantage in terms of flexibility, as it does not require the use of physical elements such as markers to access educational content. This makes it more practical than marker-based methods and allows students to learn easily anytime and anywhere.

From an effectiveness perspective, this approach has demonstrated the ability to increase student interest in learning. Interactive features such as the ability to rotate, zoom, and explore 3D models from various angles provide a learning experience unattainable with conventional methods. Furthermore, the quiz feature included in the application provides students with the opportunity to directly measure their understanding of the material being studied. Evaluation results showed that the majority of students were able to answer the questions effectively, confirming the effectiveness of this approach.

Overall, the implementation of markerless AR technology in biology learning at SMAN 1 Bulakamba produced very positive results. Students not only gained a deeper understanding but also experienced increased motivation and engagement in the learning process. This research confirms that AR is a learning tool with significant potential for wider adoption, not only in biology but also in various other educational fields. This approach makes learning more engaging, interactive, and able to address the challenges of teaching complex material.

Implications

The results of this study indicate that the implementation of AR technology has a significant positive impact on students' learning experiences. With more interactive learning methods, students not only gain better understanding but are also motivated to be more active in the learning process. Therefore, educational institutions are expected to begin considering integrating AR technology into their curriculum. This step is expected to create a more dynamic, engaging, and relevant learning environment to meet students' needs in the digital age.

Application Appearance

a. Min Menu Appearance

This page contains two main menus: the Start button and the Exit button. The Main Menu Appearance is as follows.

Figure 1. Main Menu Display

b. Start Menu Display

This page displays the AR Camera or opens the camera on your smartphone. A 3D object will appear, and this display only has a Next button on the right.

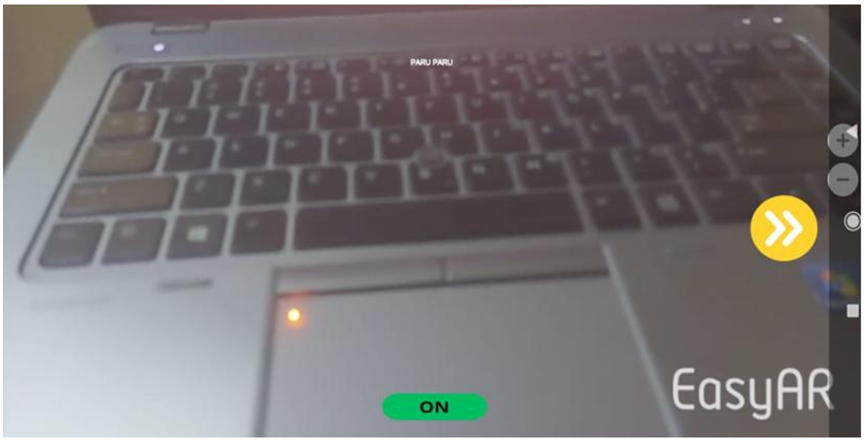

Figure 2. Start Menu Display

c. Lung 3D Object Display

This 3D object display is available in the Start menu when the camera appears. The user can point the camera forward. If it doesn't appear, try sliding your finger to make it visible. You can zoom in and out as desired. The Lung 3D object can be seen in the following image:

Figure 3. 3D Object View of the Lungs

Here's the material about the Lungs:

The lungs are the main organs in the respiratory system, functioning to take in oxygen from the air and expel carbon dioxide as a byproduct of respiration.

The human lungs consist of two parts:

1) Right Lung: Has three lobes (sections): the superior lobe, the middle lobe, and the inferior lobe.
2) Left Lung: Has two lobes: the superior lobe and the inferior lobe, which is smaller to make room for the heart.

The lungs work together with the diaphragm muscle, which helps draw air in during inhalation and exhalation. Gas exchange occurs in the alveoli, small, sac-like structures located at the end of the bronchioles.

d. 3D Object View of the Heart

This 3D object view is available in the Start menu when the camera appears. The user can point the camera forward. If it doesn't appear, try sliding it with your finger to make it visible. It can be zoomed in or out as desired. The 3D Heart object can be seen in the following image:

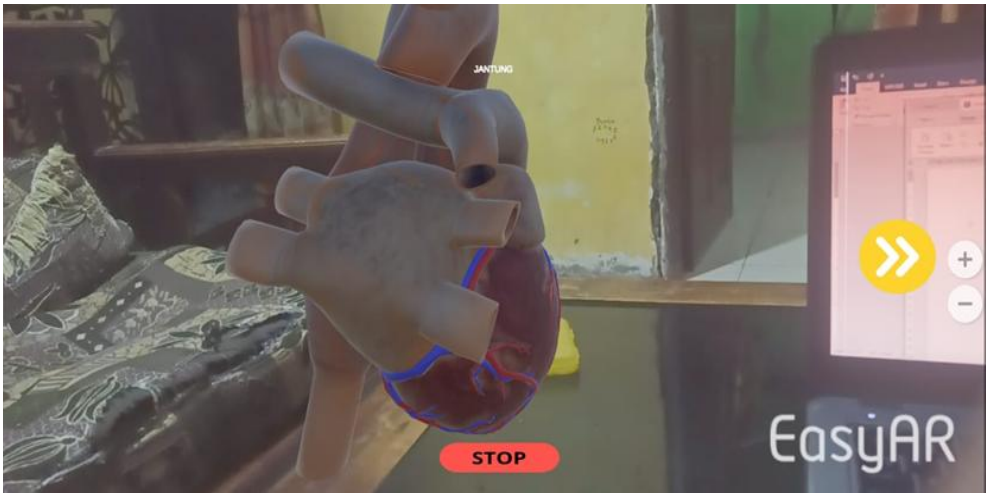

Figure 4. 3D Object View of the Heart

Here's some information about the heart:

The heart is a muscular organ that acts as the main pump in the circulatory system. The heart pumps blood throughout the body through blood vessels and ensures the distribution of oxygen and nutrients to body tissues. The structure of the heart is divided into four chambers:

a) Right and Left Atrium: Receive blood entering the heart.
b) Right and Left Ventricles: Pump blood out of the heart.

Blood flow through the heart is controlled by heart valves, which keep blood flowing in one direction. This blood pumping process is divided into two circulations:

c) Pulmonary Circulation: Blood flows from the heart to the lungs to pick up oxygen.
d) Systemic Circulation: Oxygenated blood is pumped throughout the body.

The heart works continuously at a rhythm controlled by natural electrical signals within the heart that regulate the heartbeat.

e. 3D Heart Object Display

This 3D object is displayed in the Start menu. When the camera appears, the user can point the camera forward. If it doesn't appear, try sliding your finger to reveal it. You can zoom in and out as desired. The 3D Heart object can be seen in the following image:

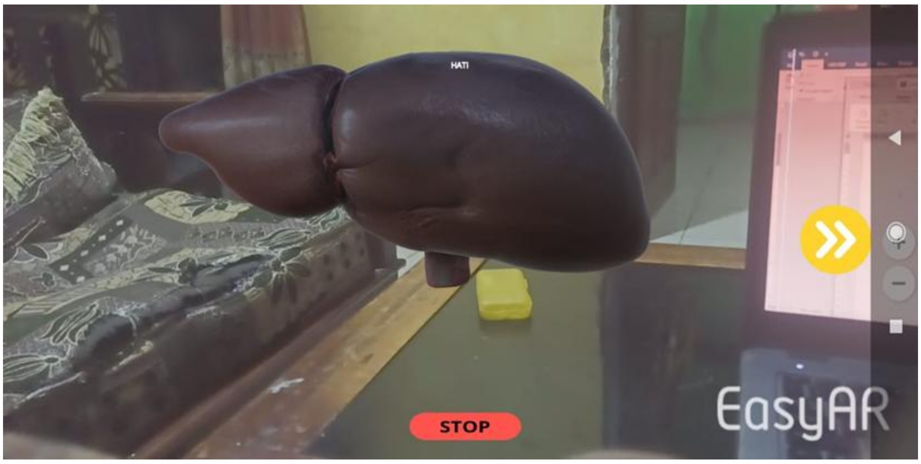

Figure 5. View of the Heart Object

Here's some information about the Liver:

The liver is the largest organ in the human body, located in the upper right abdomen, below the diaphragm. The liver has many important functions, including:

a) Nutritional Metabolism: Converts food into energy and stores some nutrients.
b) Detoxification: Filters toxic substances from the blood, including drugs and alcohol.
c) Bile Production: Bile produced by the liver aids in the digestion of fats.
d) Blood Protein Formation: Such as albumin, which is important for maintaining osmotic pressure and preventing swelling.

The liver also has the ability to regenerate, repairing itself when damaged. The liver is composed of small units called lobules, which contain tiny blood vessels and liver cells (hepatocytes) that perform metabolic functions.

f. 3D Skin Layer Object Display

This 3D object display is available in the Start menu when the camera appears. The user can point the camera forward. If it doesn't appear, try sliding it with your finger to see it. It can be zoomed in or out as desired. The 3D Skin Layer object can be seen in the following image:

Figure 6. Skin Layers

The following is material regarding the Skin Layers:

The skin is the largest organ in the human body, protecting the body from the external environment, regulating body temperature, and containing sensory receptors. The skin consists of three main layers:

a) Epidermis: The outermost layer that protects the body from infection and fluid loss. The epidermis contains melanin, which gives skin its color.
b) Dermis: The middle layer containing connective tissue, blood vessels, hair follicles, sweat glands, and oil glands. The dermis provides strength and elasticity to the skin.
c) Hypodermis (Subcutaneous): The innermost layer composed of fatty tissue. It functions to store energy and helps insulate the body.

The skin also functions in the excretory process through sweat glands, which remove toxins and help regulate body temperature through sweat evaporation.

g. Kidney Layer 3D Object Display

This 3D object display is available in the Start menu when the camera appears. The user can point the camera forward. If it doesn't appear, try sliding it with your finger to see it. It can be zoomed in or out as desired. The 3D Kidney object can be seen in the following image:

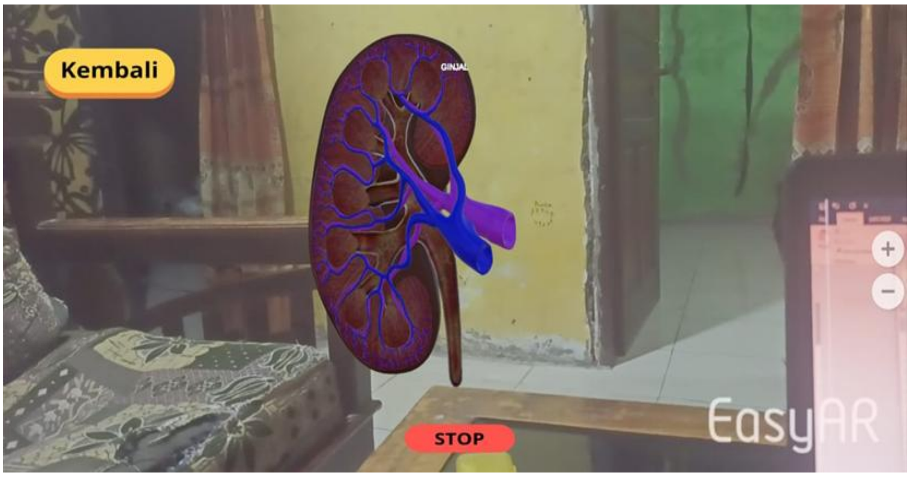

Figure 7. Kidney Object Display

The following is material regarding the Kidney Layers:

The kidneys are organs located on either side of the spine, just below the ribs. The primary function of the kidneys is to filter blood and excrete waste and excess fluid in the form of urine. The kidneys have several important functions, such as:

a) Fluid and Electrolyte Regulation: Maintaining the body's fluid balance and the concentration of ions such as sodium, potassium, and calcium.
b) Waste Excretion: Eliminating metabolic waste products, such as urea and uric acid.
c) Blood Pressure Regulation: Producing the hormone renin, which regulates blood pressure.
d) Blood pH Control: Regulating the acid-base balance in the blood.

> The kidneys contain millions of nephrons, tiny filtering units that separate harmful substances from the blood and excrete them through urine. This filtration process is essential for maintaining the stability of the body's internal environment, or homeostasis.

Based on the results of the questionnaire analysis in this study, data showed that respondents' level of understanding of the markerless Augmented Reality (AR) application for recognizing human anatomy showed very positive results. In the "Very Understand" category, 131 respondents provided answers indicating a high level of understanding of the material presented through this application. This is the highest percentage compared to other categories, indicating that this application is effective in improving students' understanding of the concepts taught.

The application of markerless AR technology has several key advantages, one of which is the ability to present interactive visualizations without the need for physical markers. This allows students to explore three-dimensional objects, such as human body parts, from various angles in real time. This capability provides a more immersive learning experience than conventional methods, such as textbooks or two-dimensional images.

The questionnaire results showed that most students were enthusiastic about using this application, primarily due to its ability to visualize human anatomy in detail and realistically. Furthermore, interactive features such as the ability to zoom in, rotate, and select specific body parts provide students with opportunities to learn independently according to their own needs. This has proven effective in helping students understand complex material in a simpler and more engaging way.

In terms of evaluation, the presence of a quiz feature in the application provides significant added value. Students can immediately measure their understanding after studying the material through the application. Questionnaire data showed that the majority of students answered the questions correctly, indicating that this learning method successfully improved their memory and comprehension. This aligns with the concept of active learning, where students who are directly involved in the learning process tend to achieve better understanding.

Overall, this study confirms that markerless AR technology is not only effective in improving students' understanding of learning materials but also increases their motivation to learn. The advantages of this technology, such as its flexibility of use and interactive visualizations, have a significant positive impact on students' learning experiences. Therefore, this technology has great potential for wider application in education, particularly for topics requiring complex visualizations such as biology.

CONCLUSION

This study successfully implemented markerless Augmented Reality (AR) technology as an educational tool for teaching human anatomy to students at SMAN 1 Bulakamba, demonstrating its effectiveness in enhancing understanding through interactive 3D visualization. The application increased students' interest and motivation by allowing them to independently rotate, zoom, and explore anatomical models, with evaluation results showing the majority of students achieved a "Very Understand" level at an average of 21.6% per question. The markerless approach offers flexible learning without requiring physical markers, making it practical for easy adoption. Future research should focus on adding interactive features such as organ function simulations and educational games, providing teacher training, expanding testing to a larger participant base, integrating the application into the curriculum, and improving technological infrastructure in schools to optimize the impact of markerless AR on immersive visualization-based education.

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