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Development Potential of AR Anatomy as an Interactive Learning Medium for Elementary Science Education

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Abstract: In the era of the Industrial Revolution 4.0 and Society 5.0, education is expected to deliver adaptive, interactive, and contextual learning experiences. One of the main challenges in elementary science education lies in teaching abstract concepts such as human anatomy, where traditional textbooks and two-dimensional images often fail to support deep understanding. Augmented Reality (AR) offers a promising alternative by enabling the real-time visualization of three-dimensional (3D) models through mobile devices. This study explores the development and potential of "AR Anatomy," a camera-based AR application designed to provide interactive visualizations of human organs for elementary students. Using a qualitative literature review of recent studies published after 2022, the analysis indicates that AR Anatomy can enhance student motivation, active engagement, and spatial understanding, while offering a cost-effective alternative to physical anatomical models. Nevertheless, limitations remain, including restricted organ coverage, lack of integrated evaluation features, and limited alignment with the national curriculum. In conclusion, AR Anatomy represents a promising step toward technology-enhanced science education at the elementary level, with further refinement needed to improve content coverage and classroom implementation.

1. INTRODUCTION

In the era of Society 5.0 and the Fourth Industrial Revolution (Industry 4.0), the education sector faces significant challenges in providing learning experiences that are not only informative but also interactive and engaging. Natural Science (IPA) subjects in elementary schools, particularly the topic of human body anatomy, are often perceived as abstract and difficult by students due to limited visualization and the absence of contextual learning media [1]. Traditional approaches relying on textbooks or verbal explanations frequently hinder students' comprehension of organ structures and functions because of inadequate visual support.

To overcome this issue, several studies have explored the development of Augmented Reality (AR)-based learning media. For example, an application implemented at SD Negeri 10 Ciamis used the MDLC method to visualize organs such as the brain, heart, lungs, liver, kidneys, and digestive system in 3D form through marker cards. Evaluation results showed

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excellent outcomes, with student engagement and comprehension reaching a score of 91.69 [2]. Similarly, research conducted in a technological university context indicated that AR could stimulate learning interest by providing interactive and self-directed 3D models [3]. However, most of these initiatives remain at the prototype stage, are not widely accessible, and lack systematic integration into elementary school curricula.

Although the potential of AR in anatomy education has been demonstrated, existing applications are still partial—often limited to a small number of organs and lacking features such as learning evaluation or curriculum alignment. Interaction models are generally simple and not systematically implemented in classroom settings. Against this background, AR Anatomy emerges as a new solution: an educational application that utilizes AR camera technology to display 3D models of human organs in real time via smartphones. In its initial version, AR Anatomy presents basic organs interactively, enabling students to explore anatomical forms and functions in a contextual manner that differs significantly from traditional print-based media.

This paper therefore aims to provide interactive 3D human organ content specifically designed for elementary students, using an AR interface that supports self-guided exploration. The application seeks to bridge gaps in prior research by offering an accessible and integrative visual medium rarely found in existing national literature. Based on this foundation, the study pursues three objectives: (1) to discuss the application of AR technology in education, (2) to examine the strengths and limitations of AR in anatomy learning, and (3) to highlight the challenges and development potential of the AR Anatomy application. In doing so, this paper not only presents a novel visual medium but also contributes to advancing science education practices at the elementary level.

2. METHODOLOGY

This study adopts a qualitative literature review approach to analyze the potential, advantages, limitations, and challenges of implementing the AR Anatomy application for elementary-level anatomy learning. A literature review was selected to provide a comprehensive understanding of current developments, identify research gaps, and highlight opportunities for innovation.

Data Sources and Selection Criteria

Relevant academic sources were collected from books, peer-reviewed journal articles, conference proceedings, and research reports published primarily within the last five years, with emphasis on studies after 2022. Earlier studies were included where necessary to provide historical context. Sources were obtained through trusted academic databases and search engines using keywords such as “augmented reality in anatomy education,” “AR in elementary science learning,” and “educational technology challenges.”

A purposive sampling technique was applied, with inclusion criteria focusing on:

1. Explicit discussion of AR in educational contexts, particularly anatomy learning at primary or secondary school levels.
2. Methodological clarity and credibility of publication.
3. Relevance to learning motivation, comprehension, or technology integration in classrooms.
4. Sources such as non-peer-reviewed reports, blogs, or incomplete studies were excluded to ensure quality and reliability.

Data Analysis

The selected studies were analyzed using a content analysis approach. The process involved:

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1. Explicit discussion of AR in educational contexts, particularly anatomy learning at primary or secondary school levels.
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4. Sources such as non-peer-reviewed reports, blogs, or incomplete studies were excluded to ensure quality and reliability.

3. RESULTS AND DISCUSSION

The Utilization of Augmented Reality Technology in Education

Augmented Reality (AR) has emerged as a transformative tool in education, capable of converting abstract concepts into interactive and immersive experiences. By enabling the visualization of three-dimensional (3D) learning objects in real time through mobile devices, AR provides learners with a richer and more engaging educational environment. Prior studies have shown that AR significantly accelerates students' conceptual understanding by allowing them to observe complex structures directly [4]. In anatomy learning, for example, students can explore organ shapes and spatial positions dynamically rather than relying solely on static illustrations.

In the AR Anatomy application, the camera-based AR interface allows students to manipulate 3D organ models—rotating, zooming, and observing from multiple perspectives. Such interactivity promotes active learning, which is consistent with constructivist principles where knowledge is built through exploration and experience. Empirical evidence supports this effect: Rachmansyah et al. (2025) demonstrated that AR-based learning enhanced students' Higher Order Thinking Skills (HOTS), including analysis and problem-solving [6].

Teacher competence is also a decisive factor in maximizing AR's impact. A primary school study indicated that teachers require specific training to integrate AR effectively into instructional practice [7]. Without pedagogical guidance, AR may be reduced to a superficial visual aid rather than a tool for deeper engagement. Therefore, teacher readiness and training become critical for the successful adoption of AR Anatomy in classroom contexts.

Overall, AR transforms educational media into interactive and immersive tools that reduce dependence on costly physical models while increasing accessibility and student motivation [4]. Its potential lies not merely in visualization, but in reshaping how learners interact with knowledge.

Strengths and Weaknesses of AR Applications in Human Anatomy Learning

AR Anatomy was developed to provide real-time 3D visualizations of human organs through smartphones. Basic organs such as the heart, lungs, brain, and kidneys can be displayed when the device camera is directed at a marker. This capability makes anatomy more tangible and less abstract compared to conventional 2D resources. For schools with limited laboratory equipment, AR Anatomy provides an affordable alternative to expensive anatomical models, confirming findings by Prasetyo et al. (2024) that AR-based media can substitute conventional teaching aids in primary and secondary education [10].

Another strength of AR Anatomy is its accessibility. The application was designed with a simple, child-friendly interface, ensuring ease of use even for elementary students. Users only need to scan a marker to display and interact with organ models, making it suitable across different educational levels—from elementary learners to higher education beginners.

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Furthermore, AR has been shown to improve memory retention, attention, and motivation through engaging visualization [11].

From a pedagogical standpoint, AR Anatomy enhances spatial understanding, which is critical in anatomy education. Students are not only able to identify organs but also comprehend their form, location, and interrelationships. Romisa et al. (2023) found that AR-based learning significantly improved students' ability to visualize anatomical structures compared to traditional textbook learning [11].

However, limitations remain. The current version of AR Anatomy only covers a limited set of organs and lacks animations or functional simulations, restricting its potential for advanced anatomy education. Essential systems such as skeletal, muscular, and reproductive systems are absent, limiting its comprehensiveness. Furthermore, the absence of assessment features—such as quizzes or pre-/post-tests—reduces its role to visualization rather than a complete learning medium. Previous AR studies that integrated quizzes reported improved information retention and comprehension [3][10].

Table 1. Strenghts and Weaknesses of AR Anatomy

Strengths	Weaknesses
Interactive 3D visualization of organs	Limited organ coverage (only basic organs)
Child-friendly and user-friendly interface	No animation or functional simulation
Cost-effective alternative to physical models	Lack of integrated evaluation tools
Increases motivation and engagement	Not fully aligned with curriculum objectives
Supports spatial understanding	Limited for advanced anatomy learners

Thus, while AR Anatomy demonstrates strong potential as an engaging learning tool, further development is required to expand content coverage, integrate evaluation, and align with curriculum standards.

Use Case Design of AR Anatomy

The AR Anatomy application was designed with three main use cases reflecting its educational scenarios:

1. Start AR – Activates the smartphone camera to scan a marker and display a 3D organ model.

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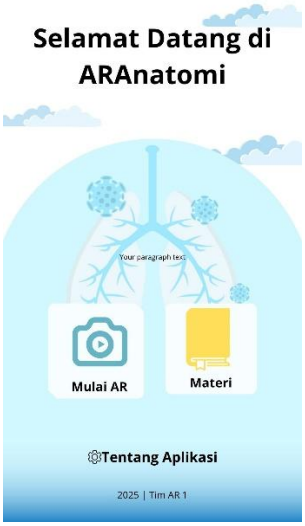

Fig 1. AR Anatomy main menu interface

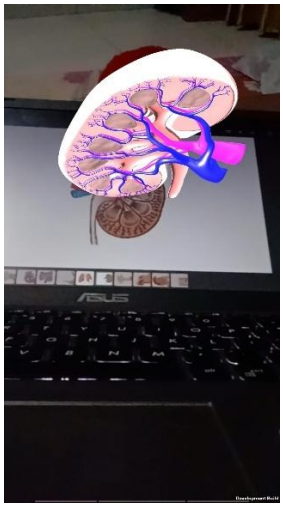

Fig 2. Real-time AR visualization through marker scanning.

2. Materials – Provides a list of organ images. When an organ is selected, a description of its function and location is displayed.

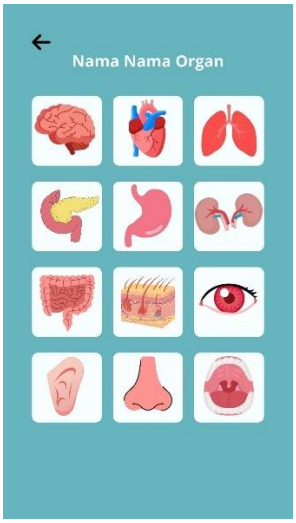

Fig 3. Example of 3D organ display.

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Fig 4. Organ content with material description.

3. About the Application – Presents general information on the purpose and educational goals of AR Anatomy.

Fig 5. Material list page.

Fig 6. About the application interface.

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In addition, markers are used to trigger AR visualization, serving as a bridge between physical and virtual learning content.

Fig 7. Example of AR marker used in the application.

To further illustrate the interaction between the user and the core functionalities, the use cases of AR Anatomy are modeled in the diagram presented below:

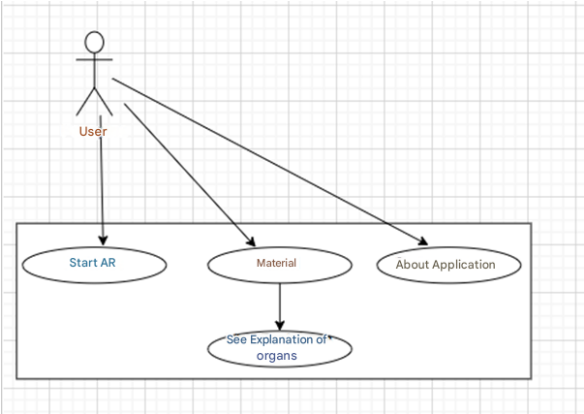

Fig 8. Use case diagram of the AR Anatomy application.

Description of Use Cases:

1. Start AR: Opens the camera to scan an organ marker and display a 3D model of the organ.
2. Materials: Displays a list of available organ images that can be selected by the user.
3. View Organ Explanation: Provides a textual description of the selected organ once tapped by the user.
4. About the Application: Offers an overview and explanation of the AR Anatomy application, including its educational goals.

The use case diagram emphasizes that the User interacts directly with three main features of the system. Each feature is designed to facilitate interactive learning and to support students' engagement with anatomical content in alignment with pedagogical objectives.

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User Experience (UX) Considerations

AR Anatomy was developed with elementary students (Grades 4–6) as its primary users. The interface adopts bright colors, large icons, and simple navigation to accommodate children's cognitive and perceptual needs. Features include:

1. Child-friendly interface with clear icons and large fonts.
2. Marker-based scanning for real-time visualization of organs.
3. Concise explanations tailored to children's reading level.
4. Simple navigation with a back button to reduce confusion.

The UX design ensures accessibility, interactivity, and enjoyment, which align with constructivist learning approaches by encouraging exploration. By providing an engaging yet simple interface, AR Anatomy successfully integrates user experience principles with pedagogical goals.

Challenges and Development Potential of the AR Anatomy Application

Despite its promise, AR Anatomy faces several challenges in classroom implementation: disparities in digital infrastructure, limited teacher competence, risk of cognitive overload, lack of curriculum integration, sustainability issues, and data privacy concerns [12][13].

Table 2. Challenges and Development Potential of AR Anatomy

Challenge	Description	Recommendation
Infrastructure	Limited device and internet access	Provide offline features; institutional/government support
Teacher competence	Lack of pedagogical integration	Conduct structured teacher training
Cognitive load	Visual complexity may overwhelm young learners	Simplify interface, use essential features
Curriculum integration	Content not aligned with national curriculum	Develop curriculum-linked modules
Sustainability	Requires funding and maintenance	Build institutional/government partnerships
Privacy & security	Camera-based use raises data protection concerns	Implement strict privacy protocols

4. CONCLUSION

The present study highlights the potential of the AR Anatomy application as an innovative learning medium for human anatomy at the elementary school level. Designed to provide interactive and visual experiences, the application addresses the challenges of teaching abstract science concepts and fosters greater student motivation and engagement. The findings suggest that the study's objective—to conceptualize an AR-based tool for enhancing students' understanding of human organs—has been achieved. However, limitations remain, including the absence of empirical classroom trials, restricted organ system coverage, lack of integrated assessment features, and limited curriculum alignment. Future research should focus on testing the application in real classroom environments, expanding content coverage, and incorporating evaluation mechanisms. With further refinement, AR Anatomy has the potential to become a relevant and impactful digital solution for modern science education.

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