

Design and Evaluation of an Android Augmented Reality Application for Human Rib Anatomy Education

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HOW TO CITE:

Zulfan Heri, Puji Ratno, Haris Kurniawan, Nono Hardinoto, Ahmad Indra Harahap (2026) Design and Evaluation of an Android Augmented Reality Application for Human Rib Anatomy Education
International Journal of Special Education, 41(22s), 644 - 658

ABSTRACT:

Visualization plays a crucial role in anatomy education. Recently, education in developing countries has remained heavily reliant on two-dimensional media and limited laboratory teaching aids, which are insufficient for depicting complex spatial relationships. The study of human rib anatomy requires more effective visualization to support understanding. Although augmented reality (AR) has been introduced to address these limitations, existing research often focuses primarily on visualization aspects without incorporating comprehensive technical evaluation and quantitative user experience analysis. This study aims to develop a marker-based augmented reality application for interactive visualization of the human rib skeleton on an Android platform and to evaluate its technical performance and user experience. The proposed system integrates three-dimensional modelling developed in Blender with real-time rendering in Unity and marker recognition using the Vuforia SDK. The application enables users to visualize the rib cage structure in three dimensions and interact with the model through rotation, zooming, and anatomical information features. The system was evaluated through marker detection testing, interaction feature testing, and user evaluation involving 30 respondents. Experimental results indicate that the system can reliably detect markers within a distance range of 20–160 cm and a viewing angle between 0° and 45°, while maintaining stable visualization of three-dimensional objects. Usability evaluation results show an average score of 4.69 out of 5, with a user acceptance level of 93.8%, indicating high usability and positive user perception. The proposed AR application provides effective interactive visualization and reliable system performance. It demonstrates strong potential as an innovative learning tool to enhance anatomy education through immersive and accessible digital learning environments.

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Keywords: Augmented Reality, Marker Detection, Human Rib, System Performance.

Introduction

The ribs (costae) are anatomical skeletal structures that protect vital organs in the chest cavity, such as the heart, lungs, and liver (Rosa, 2023). Generally, humans have 12 pairs of ribs: seven pairs of costae verae, three pairs of costae spuriae, and two pairs of costae fluctuantes (Goh & Anderson, 2025). This structure is interconnected with the sternum (os sternum) and the spine, thereby forming a complex thoracic cavity (Luo et al., 2023). The complexity of the shape, position, and interrelationships of the ribs necessitates clear spatial visualization for optimal understanding, particularly in the context of anatomy education.

However, anatomical learning media in developing countries are still dominated by two-dimensional textbooks and laboratory teaching aids (Erlindriyani et al., 2025). Two-dimensional images are lack to comprehensively illustrate the depth, orientation, and spatial relationships between bone structures. The limitations of 2D representations and their accessibility pose problems for the learning process: how to provide more interactive, realistic, and accessible visualization media to understand the three-dimensional structure of the ribs more effectively.

Augmented Reality (AR) is a technology that can integrate 3D virtual objects into the real environment in real time (Efendi & Atmarizon, 2024; Küsbeci, 2023). The best practice of this technology is used as a medium and learning experience. A number of previous studies have shown that AR has the potential to increase student motivation, understanding, and engagement in anatomy

learning. Several studies have developed AR technology for learning purposes, AR into gross anatomy education (Bork et al., 2021), anatomy for medical education (Boyanovsky et al., 2024; Neri et al., 2024), 3D holographic models for anatomy education (Uribe et al., 2023), training of medical bioengineers (Corciovă et al., 2023), etc. However, the scope of learning is very broad, thus the application is not suitable for elementary to intermediate level learning. In addition, although the results of these studies show an increase in positive user perception, most studies still focus on application development without detailed technical analysis of system performance or evaluation of user experience using a systematic quantitative approach.

Furthermore, several studies specifically focus only on rib visualization with 360° rotation, magnification (zoom), limited anatomical labeling, and limited marker stability testing (Leeuwen et al., 2023; Mejía et al., 2023; Teófilo et al., 2018). In addition, there have not been many studies that combine technical evaluation of the system (e.g., marker detection accuracy and 3D object stability) with user perception evaluation using standardized instruments. This indicates a research gap in the integration between the engineering aspects of AR systems and the evaluation of their effectiveness.

Based on this gap, this study aims to develop and evaluate a marker-based AR application on a mobile platform for interactive 3D visualization of the human rib skeleton. This research not only focuses on technical implementation using Unity and Vuforia, but

also analyzes system performance (marker detection distance and object stability tests) and evaluates user experience through a quantitative approach. The contribution of this research lies in the integration of structured AR system design and empirical user evaluation.

2. Methodology

The research methodology refers to the stages of designing, developing and evaluating an AR system. The overall AR system workflow consists of three main modules (Figure 2.1): (1) data preparation, (2) 3D modeling and asset development, and (3) AR application. The architecture integrates Blender for 3D asset creation, Unity for application development and rendering, and

Vuforia Cloud Database for marker recognition and tracking.

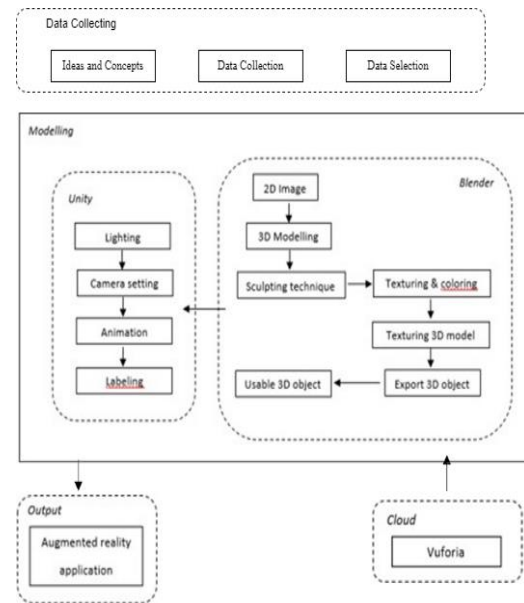


Figure 2.1: The AR system workflow

2.1. Data Preparation

The workflow begins with the data preparation stage, which includes idea formulation, data collection, and data selection. This phase ensures that both the visual assets and the tracking targets are anatomically and technically valid before

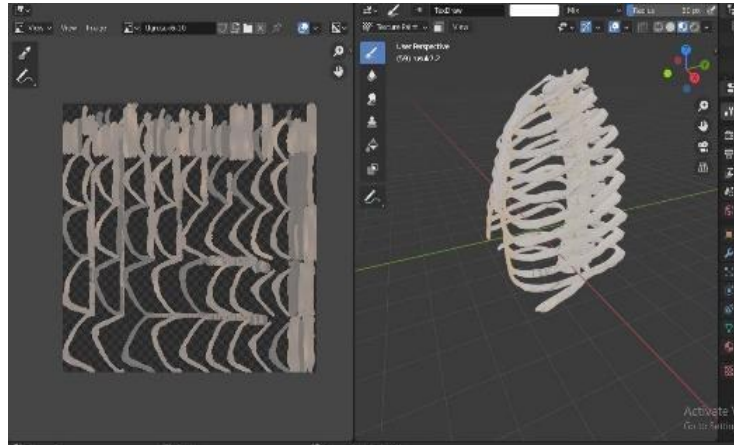
entering system development. Anatomical references were obtained from Sobotta's Clinical Atlas of Human Anatomy (Paulsen & Waschke, 2018) to ensure structural accuracy of the rib skeleton model. These markers were used as triggers to display three-dimensional objects of the human rib skeleton.



Figure 2.2: Image markers used

2.2. Participants Modelling and Asset Development This study used a marker-based tracking augmented reality method. The method displays 2D or 3D virtual

objects using image markers registered in the system database. The system scans the markers through an Android device camera and displays the corresponding 3D objects in



real time. This method is chosen for its accuracy and ease of implementation in

learning applications. This research conducted the modeling process in Blender with the steps as shown in Table 1.

Table 1. Software Configuration

Steps	Explanation
2D Image Referencing	Selected anatomical atlas images are imported as visual guides (shown in Figure 2.2).
3D Modeling (Sculpting Technique)	The rib skeleton is created using polygonal modeling with sculpting techniques to refine anatomical details, shown in Figure 2.3
Texturing and Coloring	Surface texture and coloring through the UV unwrapping process are applied to make objects appear more realistic (shown Figure 2.4).
Texture Baking	to optimize rendering performance in Unity
Exporting 3D Assets	The finalized 3D object is exported in .obj format along with texture files

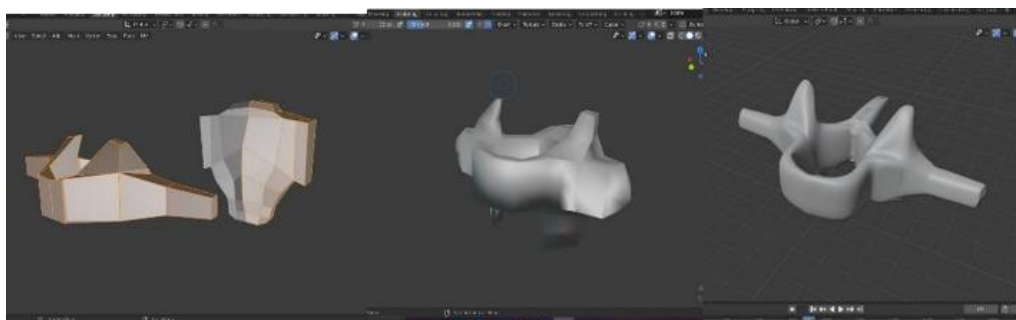


Figure 2.3: The process of sculpting 3D objects

Figure 2.4: Texturing process

After blender process, the system proceeds to AR application development in Unity 3D game engine, integrated with the Vuforia

SDK (shown in Figure 2.5). The Vuforia SDK plays a role in the process of marker detection, object tracking, and displaying

three-dimensional objects in real time on the Android device screen (Juniawan et al., 2019). Continuous tracking ensures spatial stability

of the object even with minor camera movements.

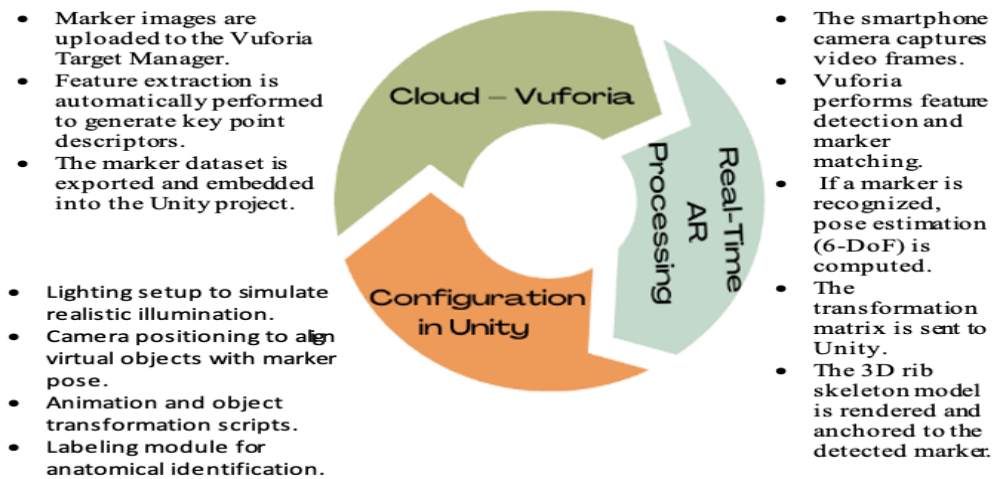


Figure 2.5: AR integration and application development

Software and Hardware Configuration

This study employs a specific software (Table 2) and hardware configuration (Table 3) to

support the development and execution of the augmented reality application, including tools for 3D modeling, AR tracking, and mobile-based visualization.

Table 2. Software Configuration

Software	Software Configuration
Laptop ASUS X441U	OS Windows 11 Home 64 bit
	Game Engine (Unity 3D 2019.4.23f1)
	SDK (SDK V10.7)
Realme XT	OS (Android pie 9, Color OS 6)

Table 3. Hardware Configuration

Hardware	Hardware Configuration
Laptop ASUS X441U	Prosesor (Intel Core i3-6006U 2.0 GHz)
	RAM (4 GB)
	Harddisk (1 TB)
	Grafik (NVIDIA GeForce 920MX 2GB)
	Screen Resolution (1366 x 768 pixel)
Realme XT	Chipset (Adreno 616)

	CPU (Snapdragon 712, Octa-core 2x2,3 GHz & 6x1,7 GHz)
	Memory (128 GB)
	Rear Camera : 64 MP, 8 MP (ultrawide) Front Camera : 16 MP
	Screen Resolution (1080 x 2340 pixels)

2.4. Participants

The user evaluation involved 30 participants from the Faculty of Sport Science at Universitas Negeri Medan who voluntarily participated as representative users of digital anatomy learning media. Prior to the evaluation, participants were introduced to the augmented reality (AR) application and instructed on how to operate it using an Android smartphone. During the evaluation session, participants interacted with the application by scanning the provided markers and exploring the three-dimensional rib anatomy model through interactive features such as zooming, rotation, and anatomical information display. After the interaction session, participants completed a usability questionnaire assessing visualization clarity, interface usability, interaction comfort, and overall learning experience. The collected responses were subsequently analyzed using statistical methods to evaluate the usability and user acceptance of the developed AR application.

2.5. Evaluation Method

The evaluation of the proposed augmented reality (AR) system was conducted through three stages: marker detection performance testing, interaction feature testing, and usability evaluation. Marker detection testing assessed the system's ability to recognize image markers and maintain stable three-dimensional visualization under varying

conditions, including camera distances ranging from 20 cm to 220 cm and viewing angles of 0°, 30°, 45°, 60°, and 75°, in order to determine the operational range and reliability of the marker-based tracking system. Interaction feature testing verified the functionality and responsiveness of implemented features, including zoom in, zoom out, object rotation, and virtual buttons for displaying anatomical information. Finally, usability evaluation was conducted using an eight-item questionnaire completed by 30 participants after interacting with the application. Responses were measured using a five-point Likert scale (1 = strongly disagree, 5 = strongly agree) and analyzed using descriptive statistical methods, including mean, standard deviation, and variance, to evaluate user perception and determine the level of system usability and acceptance.

3. Results

This chapter presents the results of the augmented reality application implementation and testing for human rib anatomy learning. The results include 3D object implementation, marker testing, application feature testing, and user evaluation.

3.1. AR Application Interface

This section describes the results of implementing an augmented reality

application developed to visualize the anatomy of the human ribs. This application was designed for the Android platform using Unity 3D integrated with the Vuforia SDK for marker-based tracking. User access first encounters a loading page and an

introduction to the AR application. The main interface of the AR application consists of several features, including the main menu, augmented reality camera interface, and anatomy information panel.

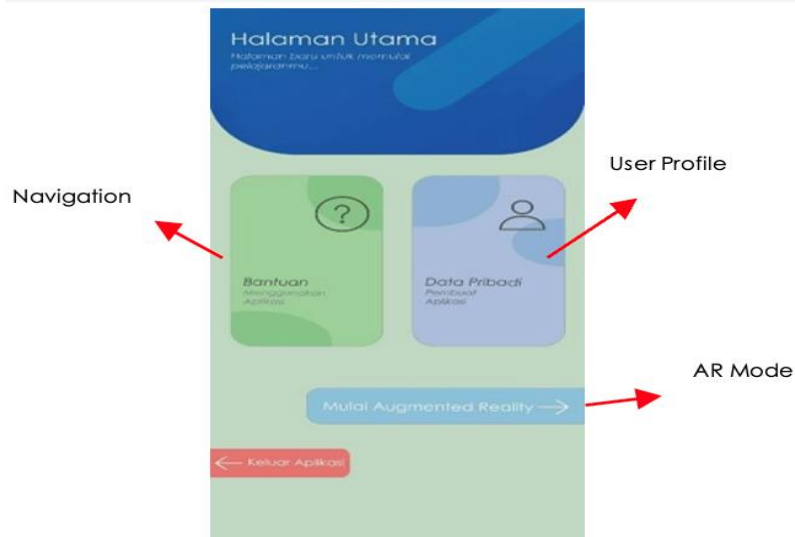


Figure 3.1: Main menu page

The main menu provides navigation options for guidance the application, user profiles, access to AR mode, and exiting the application (shown in Figure 3.1). Enabling

AR mode activates navigate to the Human rib parts menu (shown in Figure 3.2) and the smartphone camera can scan markers and display a 3D rib model in real time.

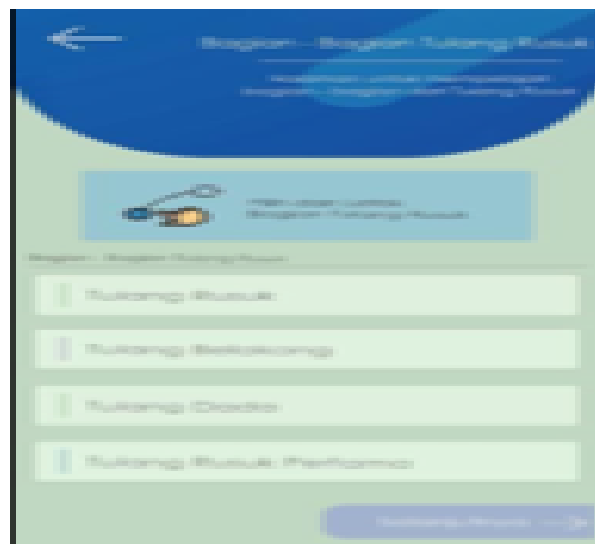


Figure 3.2: Human rib parts menu page

The results of the implementation of the 3D human rib skeleton object are shown in Figure 3.3. These 3D models are displayed on

markers scanned by the Android device's camera. Every 3D image is accompanied by a description and supports the process of

learning human rib anatomy. In addition, the developed application provides interactive features such as zoom in, zoom out, and rotate, which allow users to observe three-dimensional objects from various angles. Users can interact with objects using touch

gestures such as zooming in, rotating, and adjusting the viewing angle. This interactive visualization allows users to explore the rib cage structure more effectively than with 2D learning media.

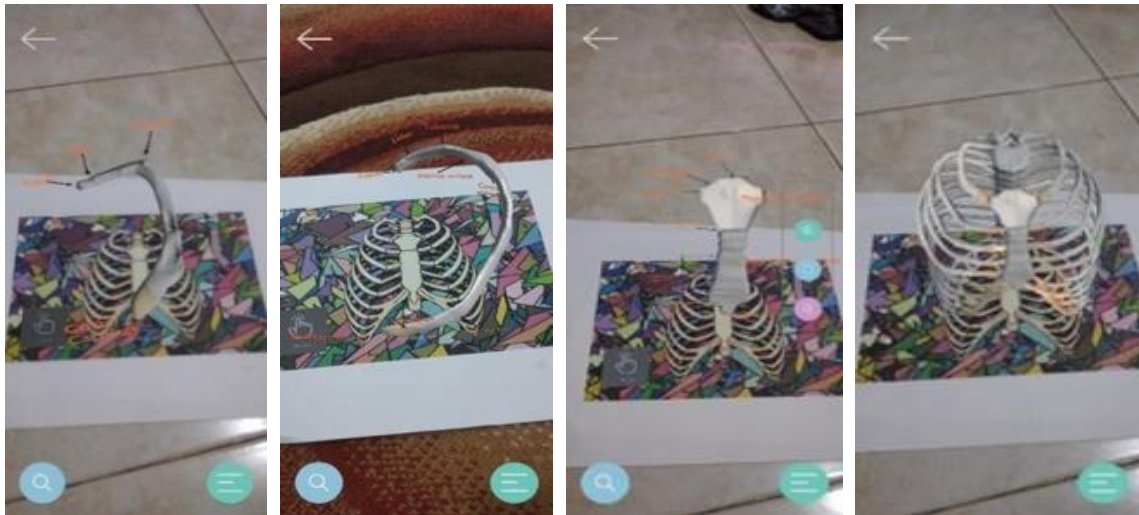


Figure 3.3: AR view of human rib cage skeleton

3.2. Market Detection Performance

To evaluate the robustness of the marker-based tracking system, a series of experiments were conducted to test the system's ability to recognize markers and maintain stable three-dimensional object visualization. The testing procedure focused on analyzing the performance of marker recognition at varying distances between the camera of the Android device and the marker, as well as elevation angles. This evaluation aims to determine the operational

range within which the augmented reality system can reliably recognize markers and display virtual objects.

The experiment was conducted in various phases with scanning distances ranging from 20 cm to 220 cm. During the testing process, the system scanned the markers using a mobile phone camera and attempted to detect and render the corresponding three-dimensional rib model in real-time. The results of the marker distance tests are presented in Figure 3.4.

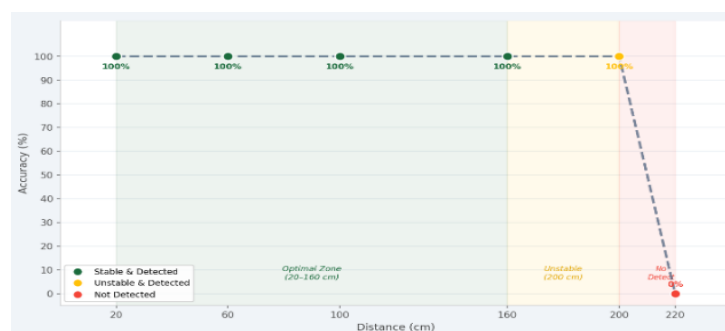


Figure 3.4: Distance test on markers

Based on the experimental results, the system successfully detected markers, displayed, and visualized 3D objects stably at distances between 20 cm and 160 cm, with a detection success rate of 100%. In other words, the AR application was able to scan markers and render virtual objects robustly within that distance range. The AR application begins to show instability at a scanning distance of 200 cm. In essence, the marker can still be detected by the system; however, the visibility of the displayed three-dimensional object captured by the camera decreases. At a distance of 220 cm, the system is no longer able to detect the marker, and as a result, the virtual object cannot be rendered. These results indicate that the optimal detection range of the marker-based augmented reality system is between 20 cm and 160 cm. In addition, this research also analyzes Marker detection based on viewing angle. The angles used are 0°, 30°, 45°, 60°, 75°. Table 4 shown experiments result that marker detection functions optimally when the camera is placed directly in front of the

Detection performance is influenced by several factors, including the resolution of the mobile device's camera, the size and quality of the printed marker, and the lighting conditions during the scanning process. At 20 cm to 160 cm with a success rate of 100%, and the three-dimensional objects displayed are stable. At a distance of 200 cm, the marker can still be detected, but the three-dimensional object begins to show instability. Meanwhile, at a distance of 220 cm, the marker cannot be detected by the system. These results indicate that the optimal detection distance for markers is between 20 cm and 160 cm. This condition is influenced by the quality of the device's camera, the size of the marker, and the lighting conditions during testing.

marker. At angles > 60°, detection accuracy decreases because the marker image becomes distorted from the camera's perspective. Meanwhile, at angles > 75°, the AR application cannot scan.

Table 4. Marker Detection Based on Viewing Angle

View Angle	Detection Result
0°	Detected
30°	Detected
45°	Detected
60°	Partially Detected
75°	Not Detected

3.3. System Interaction and Visualization

This study evaluated interaction features. It aims to ensure that the AR application meets functional and responsive aspects (Teófilo et al., 2018) in visualizing the three-dimensional rib model. The interaction features tested include zoom in, zoom out, rotation, and

virtual button functionality. These features allow users to explore the anatomical model more intuitively thru a touch screen interface.

The zoom in and zoom out features allow users to adjust the scale of three-dimensional objects to observe anatomical structures more clearly. The rotation feature enables the

virtual thoracic cavity model to be rotated up to 360 degrees, allowing users to examine anatomical structures from various angles. Additionally, the virtual button feature is

designed to provide additional information related to specific parts of the rib anatomy when selected by users.

Table 5. Interaction Feature Testing Results

No	Interaction	Function	Result
1	Zoom in	Shrink objects	Functioned properly
2	Zoom out	Enlarge object	Functioned properly
3	Rotate	Rotate object up to 360 degrees	Functioned properly
4	Visual button	Displaying information	Functioned properly

The results of the interaction feature testing are summarized in Table 5. The testing results show that all interaction features function as expected and respond accurately to user input. This indicates that the implemented interaction mechanisms support real-time exploration of the anatomical model by users.

3.4. Usability Evaluation

This section presents the user evaluation results. The evaluation assesses the usability and user acceptance of the AR application. This evaluation involved 30 respondents (student at the Faculty of Sports Science of Medan State University) who directly interacted with the AR application and completed a questionnaire. There are eight questions, addressing aspects of system usability, visual clarity, interaction comfort, and overall user experience. Each question is

rated using a Likert scale with a range of 1 (strongly disagree) to 5 (strongly agree). The questionnaire adopts from previous study (Rahmat et al., 2023; Stojšić et al., 2022).

The questionnaire responses were analyzed using descriptive statistics, including mean, standard deviation, and variance (Al Jasser et al., 2019; Suhonen et al., 2008). The results shown in Table 6. The average scores for each question are range between 4.33 and 4.93. It shows that respondents generally gave a positive evaluation of the application. The standard deviation values range from 0.25 to 0.71, indicating that the responses are relatively consistent among users. Meanwhile, the variance values range from 0.07 to 0.51, further confirming that the response distribution is stable and does not vary significantly among respondents.

Table 6. Statistical Descriptive of Survey Responses

No	Evaluation Item	Mean	Std. Dev	Var.	No
1	3D anatomical objects are clearly visualized	4.87	0.35	0.12	1
2	Anatomical parts of the 3D object are clearly displayed	4.8	0.41	0.17	2
3	Labels and anatomical information are clearly presented	4.47	0.51	0.26	3

4	Feature layout is easy to understand	4.33	0.71	0.51	4
5	All application features function properly	4.67	0.48	0.23	5
6	The application is easy to use	4.87	0.35	0.12	6
7	The interface appearance is attractive	4.6	0.62	0.39	7
8	The application provides interactive learning	4.93	0.25	0.07	8

To measure the overall user acceptance level, the User Acceptance Score is calculated by comparing the total score obtained with the maximum possible score. The results show that the application achieved a user acceptance score of 93.8%, indicating that the system is well-received by users and is considered useful and easy to use during interactions. Overall, the results of the user evaluation demonstrate that the developed augmented reality application provides a positive user experience, stable performance, and high acceptance among users.

3.5. Comparison Previous Study

This study developed a marker-based AR application for visualizing human rib anatomy and evaluated its performance through several system and user-based

evaluation metrics. Table 7 shown summary of system evaluation. The experimental results show that the system is able to detect markers effectively within a distance range of 0 –160 cm and a viewing angle between 0° - 45°, enabling stable visualization of three-dimensional anatomical objects during operation. In addition, all interaction features provided in the application, including zoom, rotation, object selection, and information display, functioned properly and allowed users to manipulate the 3D rib model smoothly. The user evaluation results also demonstrate a high level of usability, with an average usability score of 4.69 out of 5 and a user acceptance level of 93.8%, indicating that the developed AR application is easy to use and well received by users for learning human rib anatomy.

Table 7. Summary of System Evaluation

Evaluation Aspect	Result
Marker detection distance	0 -160 cm
Marker detection view angle	0° - 45°
Interaction features	Fully functional
Object manipulation	Stable
Average usability score	4.69/5
User acceptance level	93.8 %

Several studies have explored the use of augmented reality technology to support anatomy and biology education. In general, previous research has focused on enhancing

visualization, increasing student engagement, and evaluating usability thru various assessment methods. Table 8 summarizes several related studies and compares them

with the proposed system developed in this research.

Most previous studies evaluated the application of AR learning primarily thru usability assessments and learning outcomes. For example, study (Bork et al., 2021) applied an AR system for teaching gross anatomy and evaluated usability using the System Usability Scale (SUS), obtaining a score of 80.00 ± 13.90 , indicating good system usability. Similarly, study (Arslan et al., 2020) also evaluated an AR application for biology education using SUS with an average score of 3.13 ± 0.45 on a five-point Likert scale, indicating that the application was generally well received by users.

Beside usability evaluation, several studies focus on measuring system accuracy and learning effectiveness. Study (Thabit et al., 2024), which developed an AR system to assist in rib fracture surgery procedures, evaluated the accuracy of the visualization system using the mean distance error metric, achieving an accuracy of 3.6 ± 1.7 mm. Meanwhile, study (Barmaki et al., 2019) evaluated the impact of AR on anatomy education thru learning outcome tests, reporting a statistically significant increase in knowledge retention with $F(10,133) = 3.14$. Study (Elumalai et al., 2024) assessed the level of student attention in anatomy learning using an average attention score of 4.31, indicating that AR-based learning media can enhance student engagement.

Table 8. Comparison Analysis of Previous Studies

Ref.	Learning Object	Evaluation Method	Key Finding
(Bork et al., 2021)	Gross Anatomy Teaching	System Usability Scale (SUS)	5.13 ± 2.45 on a seven-point Likert scale. SUS = 80.00 ± 13.90
(Thabit et al., 2024)	Rib fracture surgery	Mean distance error	3.6 ± 1.7 mm
(Elumalai et al., 2024)	Human anatomy	Mean score of attention	4.31
(Barmaki et al., 2019)	Anatomical Education	Learning outcome test	Enhanced Learning and Knowledge Retention ($F(10,133) = 3.14$)
(Arslan et al., 2020)	Biology Education	SUS	3.13 ± 0.45 on a five-point Likert scale.
This study	Rib anatomy	Marker detection testing, interaction testing, user evaluation (mean, variance)	SUS = 93.8%, distance test = 0 – 160 cm, angle view $0^\circ - 45^\circ$

Compared to previous studies, the system proposed in this research specifically focuses on the visualization of rib anatomy using a marker-based augmented reality approach and provides a more comprehensive system evaluation. The evaluation includes marker detection testing, interaction feature testing, and user evaluation analysis using statistical measures such as mean and variance. The results show a high user acceptance score of 93.8%, indicating that the developed application is well-received and easy to use for anatomy learning. Additionally, marker detection tests indicate that the system can reliably detect markers at a distance of 0–160 cm with a field of view range of 0°–45°, demonstrating stable object visualization performance under typical usage conditions.

Overall, the comparison shows that although previous studies primarily emphasized usability or learning outcomes, this research contributes by integrating interactive visualization features, marker detection performance evaluation, and quantitative user acceptance analysis into a single AR-based anatomy learning system. These findings highlight the potential of augmented reality technology as an effective tool to support anatomy education thru immersive and interactive learning experiences

4. Conclusion

This study presents the development and evaluation of a marker-based AR application designed to support interactive learning of human rib anatomy. This system integrates three main components: 3D anatomical modeling using Blender, real-time rendering and application development using Unity, and marker recognition using the Vuforia SDK. This application allows users to visualize the rib structure in three dimensions and interact with the model thru features

such as zooming, rotation, and anatomical information display. The proposed system aims to address the limitations of conventional two-dimensional learning media by providing an immersive and interactive visualization environment that enhances spatial understanding of anatomical structures.

Experimental evaluation shows that the developed AR system functions reliably in marker detection and object visualization. Marker detection tests indicate that the system can effectively recognize markers at a distance of 20–160 cm and an angle of view between 0° and 45°, allowing stable rendering of the three-dimensional rib model during interaction. Further testing of interaction features confirmed that all implemented functionalities, including object manipulation and information display, operated well and provided smooth user interaction in the AR environment.

User evaluation results also show a high level of usability and user acceptance. Based on feedback from 30 participants, the application achieved an average usability score of 4.69 out of 5 and a user acceptance rate of 93.8%. The relatively low variance and standard deviation indicate consistent responses among users, suggesting that this system provides a stable and intuitive learning experience. These results indicate that the proposed AR application is well-received by users and has the potential to serve as an effective supplementary learning tool for anatomy education.

The main contributions of this research can be summarized as follows. First, this research develops a mobile-based AR learning application specifically designed for interactive visualization of rib anatomy, which is still relatively underexplored

compared to broader anatomy learning systems. Second, this research integrates technical system evaluation and user-centered usability analysis, combining marker detection testing, interaction feature testing, and statistical analysis of user responses. Third, the results provide empirical evidence that augmented reality technology can enhance the quality of visualization and user engagement in an anatomy learning environment.

Although the developed system shows promising performance, some limitations still exist. The current implementation relies on

marker-based tracking, which can be affected by factors such as lighting conditions, camera resolution, and marker visibility. Future research may explore the application of markerless augmented reality approaches, such as simultaneous localization and mapping (SLAM), to enhance the flexibility and robustness of the system. Furthermore, future research could expand applications by integrating more detailed anatomical structures, adaptive learning features, and objective learning outcome assessments to evaluate the effectiveness of AR-based learning in enhancing students' conceptual understanding of anatomy.

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6. Acknowledgements

The authors fully acknowledged Universitas Negeri Medan, Indonesia for the approved fund which makes this important research viable and effective.

7. Author Declaration

Authors declare that there is no conflict of interest regarding the publication of this paper