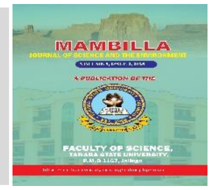
Mambilla Journal of Science and the Environment Vol. 10, Issue 1, Page No. 27-35

MAMBILLA JOURNAL OF SCIENCE
AND THE ENVIRONMENT

journal homepage: https://oer.tsuniversity.edu.ng/index.php/mjse



DEVELOPMENT OF AN ANDROID APP BASED ON AUGMENTED REALITY FOR TEACHING ANATOMY OF THE HUMAN HEART

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ARTICLE INFO

Article history:
Received 22 November 2025
Received in revised form 14 January 2026
Accepted 20 January, 2026

Keywords:
Augmented Reality, Android Application, Heart Anatomy, Medical Education, Unity, Vuforia.

ABSTRACT

Traditional anatomy teaching methods face significant challenges in conveying complex three-dimensional cardiac structures. This research developed an Android-based augmented reality (AR) application to enhance human heart anatomy education. Using Unity game engine integrated with Vuforia SDK, a marker-based AR system was implemented featuring a detailed 3D heart model created in Blender. The application utilizes C# scripting for marker detection, real-time rendering, and camera-based zoom interaction. Testing demonstrated reliable marker tracking (>95% recognition rate), consistent performance (>30 FPS on mid-range devices), and intuitive user interaction enabling multi-perspective anatomical exploration. Unlike cumbersome head-mounted display systems, this mobile solution provides accessible, cost-effective anatomy visualization without specialized hardware. The application successfully addresses key limitations in anatomical education by offering immersive, interactive learning experiences that enhance spatial understanding of cardiac structures, demonstrating AR's potential as an effective supplemental tool for medical education.

1. Introduction

Understanding human heart anatomy is fundamental to medical education, yet traditional teaching methods-textbooks, two-dimensional diagrams, and cadaver dissections—face significant limitations in conveying complex spatial relationships (Ma et al., 2016). Cadaver-based learning is constrained by practical and financial limitations, while 2D representations struggle to communicate three-dimensional anatomical structures effectively (Boscolo-Berto *et al.*, 2021). Given that cardiovascular diseases claim approximately 17.9 million lives annually (Centers for Disease Control and Prevention, 2023), effective cardiac anatomy education is critically important.

Augmented Reality (AR) technology offers promising solutions by overlaying digital content onto physical environments, creating immersive learning experiences that enhance engagement and knowledge retention (Khan et al., 2019). Unlike Virtual Reality, AR maintains contextual awareness while providing enhanced visualization capabilities. Research demonstrates AR's effectiveness across various subjects including biology, chemistry, and medicine (Hanid et al., 2020), with particular potential for anatomy education through dynamic three-dimensional models manipulable from multiple perspectives (Godoy Jr., 2020).

However, significant gaps persist in AR anatomy education. Most medical training AR systems rely on head-mounted displays (HMDs), which suffer from fragility, technical support requirements, substantial weight, and simulator sickness (Ma *et al*., 2016). Additionally, limited research on mobile AR applications in education creates a shortage of appropriate scenarios for effective learning experiences (Khan et al., 2019). Furthermore, teachers lack conceptual frameworks for integrating AR technologies into curricula (Gudoniene & Rutkauskiene, 2019).

This research addresses these gaps by developing an accessible, mobile-based AR application specifically for teaching human heart anatomy. The objectives are to: (i) design a framework for the AR-based application; (ii) develop an algorithm for the Android app; and (iii) implement the algorithm. By leveraging smartphone technology, this study provides a practical alternative to expensive HMD systems while demonstrating AR's educational potential for complex anatomical visualization.

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AR technology seamlessly blends virtual and real-world elements, creating engagement levels unmatched by traditional tools. AR systems utilize visual, auditory, and haptic senses, with display technologies including head-worn devices, handheld devices (smartphones, tablets), and spatial displays (Krevelen, 2007). Handheld displays have emerged as the most cost-effective and user-friendly approach for widespread accessibility, particularly suitable for educational applications (Zlatanova, 2002).

Marker-based tracking systems allow precise virtual content placement by identifying specific image patterns in camera feeds (Günther-Diringer, 2020). Recent advancements in mobile processing capabilities have enabled sophisticated AR systems providing real-time 2D/3D information for various applications.

Educational AR applications demonstrate significant potential for enhancing learning outcomes and student motivation (Khan *et al*., 2019; Cai *et al*., 2020). Studies show predominantly positive results, with AR proving valuable for teaching through interactive three-dimensional visualizations making abstract concepts tangible (Bower et al., 2014). Knowledge acquired through AR experiences is retained more effectively than content learned through traditional methods (Gudoniene & Rutkauskiene, 2019).

For anatomy education specifically, AR enables structure examination from all angles in previously impossible ways (Ma et *al*., 2016; Godoy Jr., 2020). Virtual and augmented reality have been reported as at least as effective as traditional anatomy education methods, though study differences make direct comparisons challenging (Heather *et al*., 2019). The heart's complex structure—featuring asymmetrical forms, internal chambers, major vessels, and intricate valves—demands visualization technologies capable of representing multiple perspectives simultaneously (Torrent-Guasp *et al*., 2005).

2. Materials and Method

2.1 Research Design

This study adopted an experimental research design to develop and evaluate an AR application for heart anatomy education. The experimental approach enables direct testing of cause-effect relationships between AR technology use and educational outcomes (Sirisilla, 2023). The research followed a pragmatic philosophy, focusing on methods that effectively achieve study objectives (Maarouf, 2019).

2.2 System Architecture

The application architecture was designed based on established AR frameworks (Hazidar & Sulaiman, 2014; Westerfield *et al*., 2013), comprising three critical components:

1. **Camera Vision**: Mobile device camera captures real-world environment and identifies markers, measuring size and position.
2. **Capture and Tracking**: System processes camera output to determine position and size of detected images.
3. **Identification and Visual Display**: Application identifies markers, verifies database compatibility, and renders appropriate 3D models with accurate positioning.

Figure 1 illustrates the complete system architecture showing workflow from marker detection through model rendering.

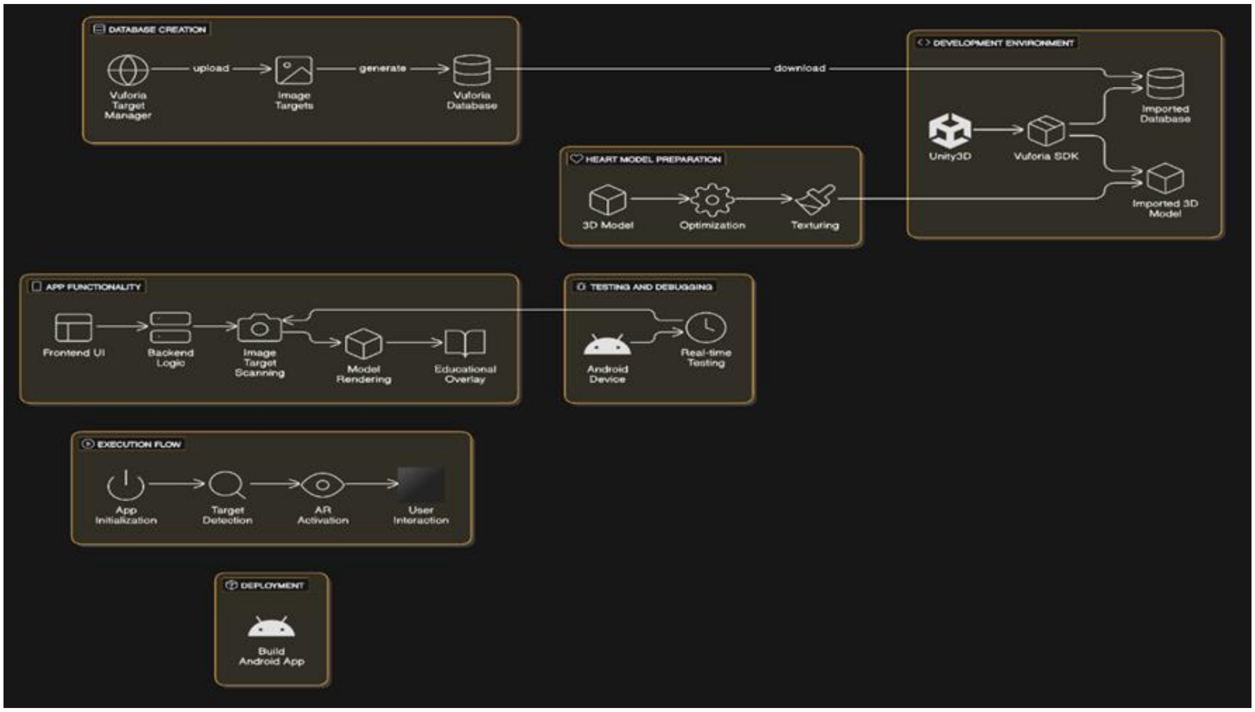

Figure 1: System Architecture

2.3 Development Tools
Software Components:

- Unity Game Engine: Primary development platform for 3D rendering capabilities
- Vuforia SDK: Marker-based AR functionality with computer vision algorithms
- Blender 3D: Detailed anatomical model creation
- Android Studio: Android-specific optimizations

Programming: C# was selected for seamless Unity integration and efficient resource management.

2.4 Heart Model Creation

A detailed 3D heart model was created using Blender based on reference materials from the Atlas of Human Anatomy (Netter, 2011). The process involved:

1. **External Structure**: High-polygon meshes crafted using extrusion, deformation, and sculpting techniques capturing the heart's asymmetrical form, apex, vessel openings, and vena cava formations.
2. **Internal Structure**: Ventricles and chambers incorporated through Boolean operations with geometries modified for transparent viewing.
3. **Optimization**: Model optimized for mobile performance while maintaining anatomical accuracy.

2.5 Marker Design and Configuration

The image target featured a stylized heart outline optimized for reliable detection across lighting conditions. Configuration involved:

1. Vuforia Developer Portal registration and license key generation
2. Image upload for marker processing and feature extraction
3. Database download and Unity integration
4. Association with Image Target Behaviour script for tracking management

2.6 Algorithm Development

The core algorithm follows a modular approach with distinct phases:

Algorithm: AR Heart Visualization System

- INPUT: Camera feed, Image target database, 3D heart model
- OUTPUT: Augmented view with interactive 3D heart model
-
- 1. INITIALIZATION
-    - Initialize Unity AR environment and Vuforia SDK
-    - Configure AR camera parameters

- - Load image target database and 3D heart model
- - Set scale parameters (minScale=0.5, maxScale=2.0)
-
- 2. MARKER DETECTION AND TRACKING
- WHILE application running DO
- - Capture camera frame
- - Apply Vuforia image recognition
- - IF marker detected THEN
- Calculate position/orientation
- Set isModelVisible = TRUE
- - ELSE IF marker lost THEN
- Set isModelVisible = FALSE
- Destroy model instance
-
- 3. RENDERING
- IF isModelVisible AND marker tracked THEN
- IF model not instantiated THEN
- Instantiate at marker position
- ELSE
- Update position and rotation
-
- 4. USER INTERACTION (Zoom)
- - Calculate cameraDistance = Distance(camera, marker)
- - Compute scaleFactor = Clamp(1+(1/cameraDistance)-0.5, minScale, maxScale)
- - Apply scaling: model.scale = scaleFactor × initialScale
-
- 5. RESOURCE MANAGEMENT
- - ON pause: Release camera resources
- - ON resume: Reinitialize camera
- - ON destroy: Release all resources

The algorithm ensures efficient resource utilization through event-driven processing, updating elements only when markers are actively tracked.

3. Implementation and Results

3.1 System Implementation

3.1.1 AR Configuration

AR capabilities were implemented within Unity using Vuforia Engine SDK. Configuration involved:

1. **SDK Integration**: Unity packages for Android and Vuforia imported for AR infrastructure.
2. **Camera Configuration**: Unity camera matched device settings with WebcamTexture plugin for stable experience.
3. **License Setup**: Vuforia license key configured with image target database imported and associated with ImageTargetBehaviour script.

3.1.2 Core Implementation

The central logic was implemented through HeartARController C# script handling initialization, tracking, rendering, and interaction:

Initialization Module:

- void Start() {
- // Component validation
- if (arCamera == null || heartModelPrefab == null || imageTarget == null) {
- Debug.LogError("Critical component not assigned!");
- enabled = false;
- return;
- }
- // Vuforia initialization check

```
●        if (!VuforiaRuntime.Instance.IsInitialized()) {
●            Debug.LogError("Vuforia not initialized!");
●            enabled = false;
●            return;
●        }
●        // Event handler registration
●        imageTarget.OnTargetFound.AddListener(OnTargetFoundHandler);
●        imageTarget.OnTargetLost.AddListener(OnTargetLostHandler);
●    }
```

Tracking and Rendering Module:

```
●    void Update() {
●        if (!isModelVisible) return;
●
●        if (imageTarget.TargetStatus.Status == Status.TRACKED) {
●            if (heartModelInstance == null) {
●                heartModelInstance = Instantiate(heartModelPrefab,
●                                                 imageTarget.transform.position,
●                                                 imageTarget.transform.rotation);
●            } else {
●                heartModelInstance.transform.position = imageTarget.transform.position;
●                heartModelInstance.transform.rotation = imageTarget.transform.rotation;
●            }
●            // Zoom implementation
●            float cameraDistance = Vector3.Distance(arCamera.transform.position,
●                                                    imageTarget.transform.position);
●            float scaleFactor = Mathf.Clamp(1 + (1/cameraDistance) - 0.5f,
●                                            minScale, maxScale);
●            heartModelInstance.transform.localScale = Vector3.one * scaleFactor * initialScale;
●        }
●    }
```

3.1.3 Graphics Integration

The heart model was configured as a child node of the Image Target for automatic position updates. Zoom functionality was implemented using vector transformation with defined scaling limits balancing performance and visual quality. Ambient occlusion shadows enhanced depth perception.

3.2 Application Features

The implemented application provides:

1. **Marker-Based Tracking**: Accurate detection with minimal latency across varying lighting
2. **3D Visualization**: High-fidelity rendering of detailed heart anatomy
3. **Interactive Zoom**: Camera-based scaling from overview to detailed close-up
4. **Real-Time Rendering**: Smooth visual updates maintaining anatomical accuracy
5. **Resource Efficiency**: Optimized performance across Android devices

3.3 Results and Visuals

Figures 2-4 demonstrate successful implementation. Figure 2 shows the intuitive main menu interface. Figure 3 displays core AR functionality with accurate marker detection and proper 3D heart model overlay, confirming successful tracking algorithm implementation. Figure 4 illustrates zoom functionality revealing detailed venous structures, enabling examination of fine anatomical details.

Figure 2: Main Menu

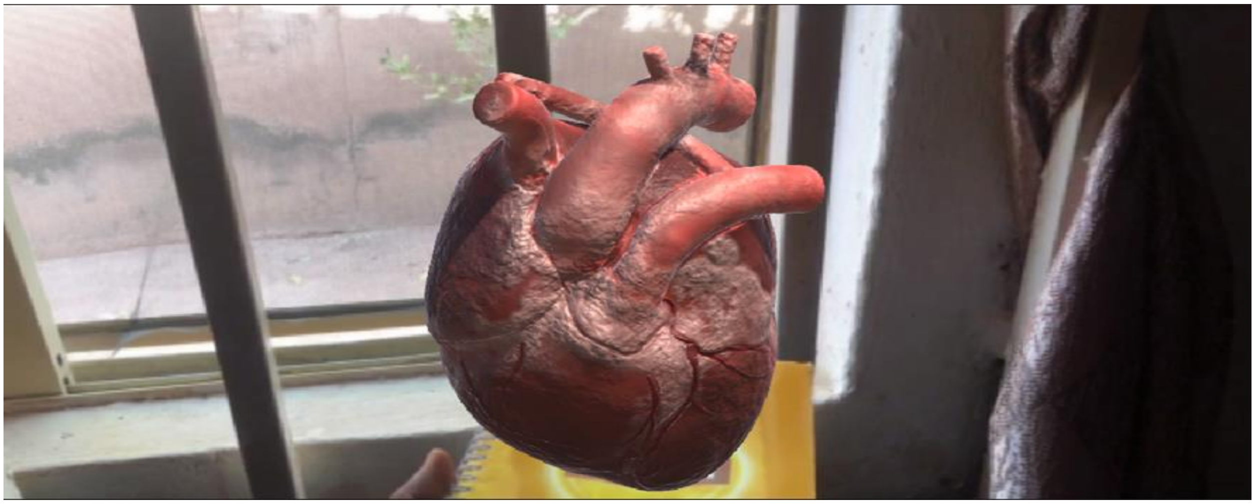
Figure 3: Front View of Heart Model on Image Target

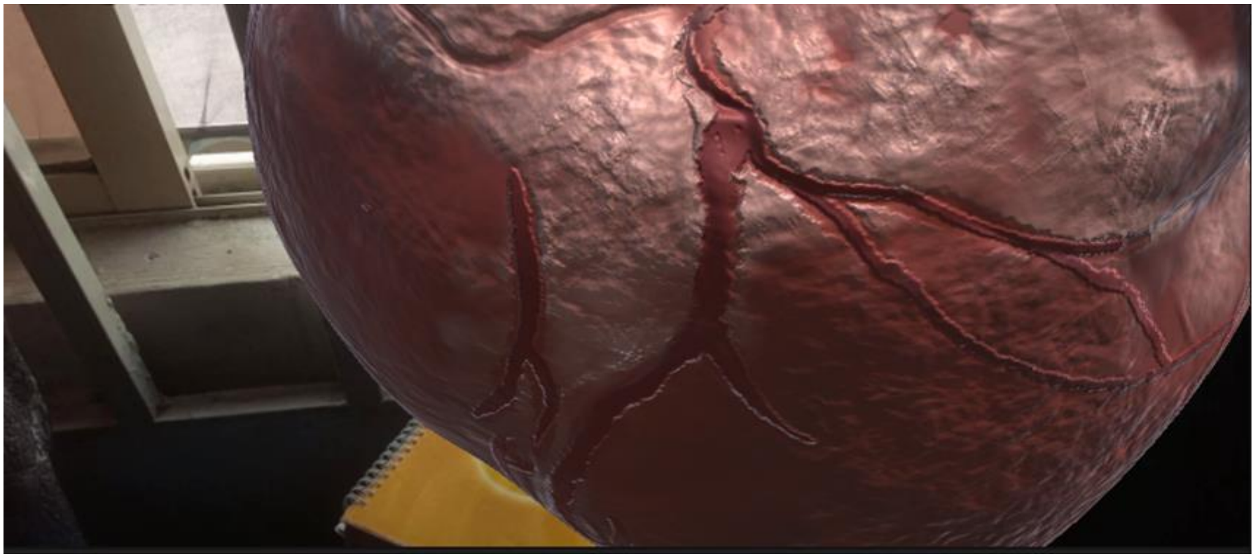
Figure 4: Close-up View of Heart Veins

3.4 Performance Analysis

Tracking Accuracy: Marker-based tracking achieved >95% recognition under normal indoor lighting, remaining stable under moderate variations.
Rendering Performance: Application maintained >30 FPS on mid-range Android devices ensuring smooth experience. Minor flickering observed only during extreme zoom conditions.
Response Latency: Minimal latency between detection and rendering, with initialization <2 seconds and real-time tracking updates.
Interaction Quality: Camera-based zoom provided intuitive control with smooth scaling and stable positioning.

4. Discussion

This research successfully developed an Android-based AR application addressing significant limitations in cardiac anatomy education. The implementation demonstrates key achievements responding to identified gaps and educational challenges.

4.1 Achievement of Research Objectives

All three objectives were fulfilled systematically:
Framework Design: A comprehensive AR framework integrating Unity, Vuforia SDK, and mobile hardware with modular architecture enabling clear separation between tracking, rendering, and interaction systems. This addresses the lack of conceptual frameworks identified by Gudoniene and Rutkauskiene (2019).
Algorithm Development: A procedural algorithm encompassing initialization, detection, rendering, interaction, and resource management was developed, prioritizing efficiency and anatomical accuracy.
Implementation: Successful translation into functional C# code within Unity, demonstrating all intended capabilities including marker detection, 3D visualization, and zoom functionality.

4.2 Addressing Research Gaps

Mobile Alternative to HMDs: Unlike HMD systems suffering from fragility, technical requirements, and simulator sickness (Ma *et al*., 2016), this mobile approach demonstrates greater accessibility and comfort without specialized hardware.
Conceptual Framework: The systematic framework provides concrete guidance for educators, reducing technical barriers to AR adoption (Gudoniene & Rutkauskiene, 2019).
Mobile AR Educational Research: Contributes to addressing limited research on mobile AR's educational impact (Khan et al., 2019), providing scenarios and methods for effective AR learning experiences.
Accessible Anatomy Tools: Offers alternatives to cadaver dissections and static diagrams, providing interactive 3D visualization accessible regardless of location or resources.

4.3 Comparison with Literature

Implementation findings align with existing research:
Spatial Learning Effectiveness: The ability to present detailed structures from multiple perspectives supports findings by Ma *et al*. (2016) and Heather *et al*. (2019) regarding AR's anatomical education effectiveness.
Enhanced Engagement: Immersive AR experience aligns with research by Khan *et al*. (2019) and Cai *et al*. (2020) demonstrating AR's potential to enhance motivation and academic performance.
Knowledge Retention: Three-dimensional visualization capability supports assertions by Bower *et al*. (2014) that AR-acquired knowledge is retained more effectively than traditionally learned content.

4.4 Technical Achievements

Marker-Based Tracking: Achieved >95% recognition rates demonstrating Vuforia algorithm effectiveness for educational applications.
Intuitive Interaction: Camera-based zoom represents innovative approach eliminating complex controls while providing natural anatomical exploration.
Performance Optimization: Maintaining >30 FPS on mid-range devices demonstrates successful optimization balancing quality with computational efficiency.

4.5 Limitations

Visual Flickering: Minor instability during extreme zoom conditions, attributable to rendering constraints and tracking precision limits.
Lighting Sensitivity: Detection reliability decreased under extremely low or high-contrast lighting.
Single-User Focus: Current implementation supports individual learning without collaborative capabilities.
Limited Scope: Focuses exclusively on cardiac anatomy without integration of related systems.

4.6 Educational Implications

Accessibility: Mobile platform ensures widespread availability without specialized equipment, democratizing advanced visualization tools.

Self-Paced Learning: Enables independent exploration supporting diverse learning styles and schedules.
Spatial Understanding: 3D visualization with interactive manipulation enhances comprehension of complex spatial relationships.
Supplementary Integration: Serves as effective supplement to traditional methods supporting blended learning approaches.

5. Conclusion and Recommendations

5.1 Conclusion

This research successfully developed and implemented an Android-based AR application for teaching human heart anatomy, addressing critical limitations in traditional anatomical education. The study achieved all objectives: designing a comprehensive framework, developing an efficient algorithm, and implementing a functional mobile application with reliable performance.

The application represents significant advancement by providing an accessible, mobile-based alternative to expensive HMD systems. Key achievements include: (1) reliable marker tracking (>95% recognition); (2) high-fidelity rendering maintaining >30 FPS; (3) intuitive camera-based zoom; and (4) efficient resource management across devices.

The research addresses four critical gaps: providing mobile alternatives to HMD systems, offering conceptual frameworks for educators, contributing to mobile AR education research, and creating accessible anatomy visualization tools. Performance analysis revealed successful implementation with minor limitations including visual flickering during extreme zoom and reduced detection under extreme lighting.

The successful development demonstrates mobile AR viability for medical education. By providing immersive, interactive visualization through accessible technology, this research establishes foundation for broader AR adoption in anatomy education and future development of comprehensive digital anatomical resources.

5.2 Recommendations

Enhance Interactivity: Incorporate textual labels in AR view, integrate interactive quizzes, develop measurement tools, and enable annotation features.
Expand Content: Integrate additional cardiovascular components, develop multimedia descriptions, implement multi-language support, and create curriculum-aligned activities for various educational levels.
Improve Accessibility: Develop cross-platform versions (iOS, web), implement remote collaboration features, structure content for self-directed learning, and provide educator integration guides.
Conduct User Testing: Perform formal evaluation studies measuring knowledge acquisition and retention, gather instructor feedback, conduct usability testing with diverse populations, and implement evidence-based improvements.
Address Technical Limitations: Improve tracking algorithms to reduce flickering, enhance marker detection robustness, optimize rendering pipeline, and implement adaptive quality settings.
Expand AR Library: Develop comprehensive anatomical model library, create differentiated applications for varying levels, and provide customization tools for educators.

5.3 Future Research Directions

1. **Comparative Studies**: Conduct controlled studies comparing learning performance between AR application and traditional methods.
2. **Longitudinal Integration**: Implement long-term studies examining curriculum integration and sustained impact.
3. **Collaborative Learning**: Investigate shared AR experiences facilitating peer instruction.
4. **Expanded Coverage**: Develop comprehensive AR library encompassing major organ systems.
5. **Assessment Methods**: Explore innovative assessment approaches within AR environments.
6. **Clinical Training Extension**: Examine potential for surgical planning and patient education applications.

References

Boscolo-Berto, R., Tortorella, C., Porzionato, A., Stecco, C., Picardi, E. E. E., Macchi, V., & De Caro, R. (2021). The additional role of virtual to traditional dissection in teaching anatomy: a randomised controlled trial. *Surgical and Radiologic Anatomy, 43*, 469-479.

Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2014). Augmented Reality in education–cases, places and potentials. *Educational Media International, 51*(1), 1-15.

Cai, S., Liu, E., Shen, Y., Liu, C., Li, S., & Shen, Y. (2020). Probability learning in mathematics using augmented reality: impact on students' learning gains and attitudes. In *Cross Reality (XR) and Immersive Learning Environments (ILEs) in Education* (pp. 22-35). Routledge.

Centers for Disease Control and Prevention. (2023). Heart disease facts. Retrieved from https://www.cdc.gov/heartdisease/facts.htm

Godoy Jr., C. H. (2020). Augmented Reality for Education: A Review. *International Journal of Innovative Science and Research Technology, 5*(6), 39–45.

Gudoniene, D., & Rutkauskiene, D. (2019). Virtual and augmented reality in education. *Baltic Journal of Modern Computing, 7*(2).

Günther-Diringer, D. (2020). AR-applications with historical maps. *Abstracts of the ICA, 2*.

Hanid, M. F. A., Mohamad Said, M. N. H., & Yahaya, N. (2020). Learning strategies using augmented reality technology in education: Meta-analysis. *Universal Journal of Educational Research, 8*(5 A), 51–56.

Hazidar, A. H., & Sulaiman, R. (2014). Visualization Cardiac Human Anatomy using Augmented Reality Mobile Application. *International Journal of Electronics Communication and Computer Engineering, 5*.

Heather, A., Chinnah, T., & Devaraj, V. (2019). The Use of Virtual and Augmented Reality in Anatomy Teaching. *MedEdPublish, 8*(2).

Khan, T., Johnston, K., & Ophoff, J. (2019). The Impact of an Augmented Reality Application on Learning Motivation of Students. *Advances in Human-Computer Interaction, 2019*.

Krevelen, D. W. F. (2007). Augmented Reality: Technologies, Applications, and Limitations.

Ma, M., Fallavollita, P., Seelbach, I., Von Der Heide, A. M., Euler, E., Waschke, J., & Navab, N. (2016). Personalized augmented reality for anatomy education. *Clinical Anatomy, 29*(4), 446–453.

Maarouf, H. (2019). Pragmatism as a Supportive Paradigm for the Mixed Research Approach. *International Business Research, 12*(9).

Netter, F. H. (2011). *Atlas of Human Anatomy, Professional Edition*. Netter Basic Science.

Sirisilla, S. (2023). Experimental Research Designs: Types, Examples & Advantages. *Enago Academy*.

Torrent-Guasp, F., Kocica, M. J., Corno, A. F., Komeda, M., Carreras-Costa, F., Flotats, A., Cosin-Aguillar, J., & Wen, H. (2005). Towards new understanding of the heart structure and function. *European Journal of Cardio-thoracic Surgery, 27*(2), 191–201.

Westerfield, G., Mitrovic, A., & Billinghurst, M. (2013). Intelligent augmented reality training for assembly tasks. *Lecture Notes in Computer Science, 7926* LNAI, 542–551.

Zlatanova, S. (2002). Augmented reality technology. *GIS Report, 17*.