

**AR Educational Suite for Primary Students’
Geometry and Literacy.**

R26-IM-005

Project Proposal Report

De Costa M.M.P. – IT22179876

B.Sc. (Hons) Degree in Information Technology Specialized in
Interactive Media

Department of Information Technology

Sri Lanka Institute of Information Technology Sri Lanka

March 2026

DECLARATION

I declare that this is my own work, and this proposal does not knowingly incorporate any material previously submitted for a degree or diploma at any other university or higher education institution, nor does it contain any material that has been previously published or written by another person apart from where proper acknowledgment is given in the text.

Name	Student ID	Signature
De Costa M.M.P.	IT22179876	

The above candidate is conducting research for their undergraduate Dissertation under my supervision.

Name	Date	Signature
Mr. Aruna Ishara Gamage	19/03/2016	

ABSTRACT

Primary school students often face difficulties in understanding spatial geometry concepts such as three-dimensional shapes, geometric nets, and volume when these topics are introduced through static two-dimensional diagrams in traditional textbooks. Visualizing how flat geometric nets transform into three-dimensional objects requires spatial reasoning skills that many young learners have not yet fully developed. As a result, students frequently struggle to interpret geometric relationships, leading to misconceptions and reduced engagement in mathematics learning. Although Augmented Reality (AR) technologies have been introduced to improve educational experiences by allowing learners to interact with 3D models in real-world environments, many existing AR learning systems mainly display predefined objects and provide only simple correct or incorrect feedback without explaining spatial errors or guiding learners toward understanding their mistakes.

To address this limitation, this research proposes an Adaptive Scaffolding and Virtual Slicing framework integrated into a mobile AR-based geometry learning system. The solution introduces a visual scaffolding mechanism using transparent ghost overlay models to help students identify and correct spatial errors during geometric construction. In addition, a virtual slicing visualization module demonstrates internal structures of geometric solids and supports understanding of volume and fractional divisions. The system will be developed using Unity 3D and ARCore, enabling markerless AR interaction on Android mobile devices. The expected outcome is an interactive educational application that improves spatial reasoning, enhances student engagement, and supports deeper conceptual understanding of geometry, while also offering potential value in the growing EdTech market.

Keywords: *Augmented Reality, Geometry Learning, Visual Scaffolding, Spatial Visualization, ARCore*

ACKNOWLEDGEMENT

I would like to express my sincere appreciation to all those who have contributed to the successful completion of this research proposal.

First and foremost, I would like to convey my deepest gratitude to my supervisor and co-supervisor for their invaluable guidance, insightful suggestions, and continuous support throughout the preparation of this research proposal. Their constructive feedback, encouragement, and academic direction greatly contributed to refining the ideas and improving the overall quality of this work.

I would also like to extend my gratitude to the academic staff of the Faculty of Computing, Sri Lanka Institute of Information Technology (SLIIT) for providing the knowledge, resources, and academic foundation that enabled me to undertake this research. The skills and understanding gained during my studies played a significant role in shaping this proposed research on **Augmented Reality based geometry learning using adaptive visual scaffolding and virtual slicing techniques**.

My sincere thanks are also extended to my research group members for their cooperation, valuable discussions, and support in developing the overall research concept and system architecture. Their collaboration helped strengthen several aspects of the proposed solution.

Finally, I would like to express my heartfelt gratitude to my parents, family, and friends for their continuous encouragement, patience, and understanding throughout this research journey. Their support and motivation have been a constant source of strength in completing this proposal.

TABLE OF CONTENT

Table of Contents

DECLARATION.....	i
ABSTRACT.....	ii
ACKNOWLEDGEMENT	iii
TABLE OF CONTENT	iv
LIST OF TABLES	vi
LIST OF FIGURES	vi
LIST OF ABBREVIATIONS	vii
LIST OF APPENDICES	vii
1. INTRODUCTION	1
1.1 Background and Context	1
1.2 Literature Review.....	2
Augmented Reality in Education.....	2
Sketch-Based 3D Modeling.....	3
Gesture Recognition and Air-Writing Systems.....	3
Markerless AR and Mobile AR Learning Systems.....	4
Visual Feedback and Scaffolding in Educational Systems	5
3D Visualization and Geometric Understanding	5
1.3 Research Gap	8
2. OBJECTIVE	10
2.1 Main Objective.....	10
2.2 Specific Objectives	10
3. METHODOLOGY	12
Research Approach	12
System Development Technologies	12
Data Collection	13
Ethical Considerations	13
Evaluation Metrics.....	13
4. HIGH-LEVEL SYSTEM ARCHITECTURE.....	14
Overview of the Proposed Solution	14
System Diagram of Components	16
Individual Component and Its Parts.....	18

Component Interactions	20
Data Flow Explanation	21
Scalability Considerations	22
Security Considerations	22
5. USER REQUIREMENTS	23
Stakeholders.....	23
Functional Requirements (FR).....	23
Non-Functional Requirements	24
6. COMMERCIALIZATION PLAN	25
Target Market.....	25
Customer Personas.....	26
Value Proposition.....	27
Revenue Model	27
Cost Estimation.....	28
Pricing Strategy.....	28
Competitive Advantage.....	29
Intellectual Property Considerations.....	29
7. BUDGET AND JUSTIFICATION	30
Hardware Costs.....	30
Software Licenses	31
Cloud Services	31
Miscellaneous Research Expenses.....	32
Total Estimated Budget.....	32
Budget Justification	33
8. WORK BREAKDOWN STRUCTURE (WBS).....	34
9. GANTT CHART.....	35
10. REFERENCES	36
11. APPENDICES	39
Appendix A – Preliminary User Interface Mockups.....	39
Appendix B – System Diagrams.....	39
Appendix C – Risk Analysis	40
Appendix D – Ethical Considerations and Participant Materials	40

LIST OF TABLES

Table 1 : Comparison of Existing Research Systems with the Proposed System.....	7
Table 2: Customer Personas.....	26
Table 3 : Estimated Development Costs	28
Table 4 : Proposed Pricing Structure	28
Table 5 : Competitive Advantage.....	29
Table 6 : Hardware Cost Estimation	30
Table 7 : Software Cost Estimation	31
Table 8 : Cloud Service Cost Estimation	31
Table 9 : Miscellaneous Expenses	32
Table 10 : Project Budget Summary	32
Table 11 : Work breakdown structure	34
Table 12 : Gantt Chart.....	35

LIST OF FIGURES

Figure 1 : High Level System Architecture	14
Figure 2 : High Level System Architecture for Individual Component.....	17
Figure 3 : Component Breakdown Diagram.....	19

LIST OF ABBREVIATIONS

AR	Augmented Reality
MR	Mixed Reality
VR	Virtual Reality
CNN	Convolutional Neural Network
RNN	Recurrent Neural Network
UI	User Interface
UX	User Experience
2D	Two-Dimensional
3D	Three-Dimensional
API	Application Programming Interface
GPU	Graphics Processing Unit

LIST OF APPENDICES

Appendix A	Preliminary User Interface Mockups
Appendix B	System Diagrams
Appendix C	Risk Analysis
Appendix D	Ethical Considerations and Participant Materials

1. INTRODUCTION

1.1 Background and Context

Spatial reasoning plays a crucial role in early education, particularly in subjects such as mathematics, engineering, and science. One of the most common challenges faced by primary school students is the difficulty in understanding the relationship between two-dimensional representations and three-dimensional geometric structures. Concepts such as geometric nets, volume calculations, and spatial transformations require learners to mentally visualize how flat shapes can fold into three-dimensional forms. However, traditional classroom teaching methods rely heavily on static diagrams in textbooks and whiteboard illustrations, which provide limited opportunities for interactive learning.

Educational research indicates that the lack of interactive visualization tools can significantly hinder the development of spatial cognition among young learners. Students often find it difficult to interpret how two-dimensional geometric nets transform into three-dimensional solids such as cubes, prisms, or pyramids. As a result, misconceptions may develop during early learning stages, which can negatively affect their understanding of more advanced mathematical concepts later in their education.

Augmented Reality (AR) technologies have emerged as a promising solution for enhancing educational experiences by allowing digital information to be integrated into the physical environment. AR enables learners to interact with virtual objects in real-world contexts, thereby improving engagement and facilitating experiential learning. Several studies have demonstrated that AR-based learning environments significantly enhance spatial understanding compared to traditional instructional methods.

Ibáñez et al. demonstrated that AR-based learning tools can improve student engagement and conceptual understanding by providing immersive visual experiences that support active learning [1]. Similarly, Radu conducted a meta-analysis of AR applications in education and concluded that AR technologies enhance motivation, retention, and spatial comprehension in learning environments [2].

Despite these advantages, many current AR educational systems focus primarily on visualization rather than interactive error correction. Students are often presented with predefined 3D models but are not provided with mechanisms that help them understand why their own geometric constructions are incorrect. In most systems, feedback is limited to simple binary indicators such as “correct” or “incorrect,” which do not provide sufficient guidance for conceptual improvement.

This research introduces an Adaptive Scaffolding and Virtual Slicing component designed to enhance AR-based geometry learning systems. The proposed solution provides visual feedback using ghost overlays and volumetric slicing techniques, allowing students to compare their constructed geometric models with correct spatial configurations. This interactive approach enables learners to visually identify errors and develop a deeper understanding of spatial relationships.

The research aligns with the Mixed Reality research cluster within Interactive Media, focusing on the integration of augmented reality, computer graphics, and educational interaction design. Furthermore, the proposed system contributes to Sustainable Development Goal (SDG) 4: Quality Education, which aims to ensure inclusive and equitable access to quality education through innovative technological solutions.

1.2 Literature Review

Recent advancements in educational technology have led to increased interest in the use of Augmented Reality (AR) to improve spatial learning and interactive education. Several research studies have explored the application of AR systems to enhance geometry education, sketch-based modeling, gesture recognition, and spatial visualization.

Augmented Reality in Education

Augmented Reality has been widely studied as an educational technology that can enhance student engagement and improve conceptual understanding. Ibáñez et al. developed an AR-based learning platform for electromagnetism education and found that students using AR systems demonstrated significantly higher levels of engagement and knowledge retention compared to traditional learning methods [1]. Similarly, Radu performed a comprehensive analysis of AR in educational contexts and concluded that AR environments promote active learning and improved spatial comprehension among students [2].

Kaufmann and Schmalstieg introduced one of the earliest collaborative AR environments designed for mathematics education, where students could interact with geometric objects in three-dimensional space [3]. Their findings showed that students using AR visualization tools developed stronger spatial reasoning skills compared to those learning through conventional methods.

Later studies continued to demonstrate the benefits of AR visualization for geometry learning. Dünser et al. developed an AR-based educational application for teaching spatial relationships and found that interactive visualization significantly improved student understanding of geometric transformations [4]. Shelton and Hedley also reported that AR environments allow students to manipulate virtual objects directly, which improves comprehension of complex spatial structures [5].

Sketch-Based 3D Modeling

Another important research area related to this study is sketch-based modeling, where two-dimensional drawings are converted into three-dimensional models. Wang et al. proposed the Sketch2Model system, which allows users to generate 3D models from hand-drawn sketches using view-aware reconstruction algorithms [6]. This approach demonstrated that sketch-based input can serve as an intuitive method for creating three-dimensional structures.

Xu et al. later explored deep learning techniques for sketch-based 3D shape retrieval, where neural networks were trained to recognize sketches and retrieve corresponding 3D models from large datasets [7]. Their research showed that machine learning algorithms can significantly improve the accuracy of sketch recognition systems.

Han et al. proposed DeepSketch2Face, a deep learning framework capable of generating 3D face models from sketch inputs [8]. Although primarily designed for graphics applications, this research demonstrates the potential of sketch interpretation techniques for transforming two-dimensional drawings into three-dimensional objects.

Gesture Recognition and Air-Writing Systems

Gesture recognition technologies are also relevant to interactive AR learning environments. Molchanov et al. developed a convolutional neural network framework for dynamic hand gesture recognition using depth sensors [9]. Their research demonstrated that CNN-based models can accurately detect hand movements and spatial trajectories.

Chen et al. proposed an online handwriting recognition system using recurrent neural networks to analyze stroke order and trajectory patterns in handwriting inputs [10]. This approach enables systems to track the dynamic motion of writing rather than simply analyzing the final shape.

Amma et al. introduced an air-writing recognition system that uses motion sensors to capture handwriting trajectories in three-dimensional space [11]. Their work demonstrated that trajectory-based recognition methods are more effective than static image classification for identifying handwriting patterns.

Markerless AR and Mobile AR Learning Systems

Recent advancements in mobile computing have enabled the development of markerless AR systems that operate on standard smartphones. Markerless AR allows virtual objects to be placed in real-world environments without relying on predefined markers, making it suitable for classroom learning scenarios.

Billinghurst et al. explored the use of mobile AR technologies for interactive learning and concluded that AR environments provide immersive experiences that enhance student engagement and collaboration [12]. Similarly, Azuma et al. highlighted that AR systems can improve visualization and spatial comprehension by combining real-world environments with computer-generated objects [13].

Bujak et al. investigated the effectiveness of AR learning environments for teaching complex spatial concepts and found that AR systems improved students' spatial reasoning abilities compared to traditional classroom teaching methods [14]. Their study demonstrated that interactive visualization tools help learners better understand geometric relationships and spatial transformations.

Another study by Dunser and Hornecker examined the usability of mobile AR systems in education and concluded that AR-based interfaces can significantly enhance learner engagement by allowing students to interact directly with virtual objects in their physical environment [15]. Despite these advancements, many AR learning applications still rely on predefined content rather than allowing students to generate and manipulate their own geometric structures. This limitation restricts exploratory learning and reduces the effectiveness of AR as a discovery-based educational tool.

Visual Feedback and Scaffolding in Educational Systems

Educational psychology research emphasizes the importance of scaffolding techniques, which provide learners with guidance and feedback that gradually improves their understanding of complex concepts.

Wood et al. introduced the concept of scaffolding as a teaching method that supports learners through guided instruction and visual assistance [16]. In technology-enhanced learning environments, scaffolding can be implemented through interactive visual cues, step-by-step guidance, or adaptive feedback mechanisms.

Chi et al. investigated intelligent tutoring systems that provide adaptive feedback based on student performance and found that guided feedback significantly improves learning outcomes [17]. Their research suggests that systems that explain errors rather than simply indicating incorrect answers are more effective for conceptual learning.

Another study by Dede explored immersive learning environments that integrate AR technologies with scaffolding techniques. The results demonstrated that immersive visualization combined with adaptive guidance improves spatial reasoning and student engagement [18].

Although these studies highlight the importance of guided feedback in learning environments, most AR educational systems still rely on binary feedback mechanisms. Students are typically informed whether their answers are correct or incorrect but are not provided with visual explanations that help them understand spatial mistakes.

3D Visualization and Geometric Understanding

Interactive 3D visualization systems have been widely studied as tools for improving spatial reasoning and geometry education. By allowing students to manipulate virtual objects directly, these systems enable learners to explore spatial relationships that would otherwise be difficult to visualize using traditional teaching methods.

Johnson-Glenberg et al. examined the role of embodied interaction in AR learning environments and found that students who physically interacted with virtual objects demonstrated improved spatial reasoning skills [19]. Their research indicates that interactive visualization tools can significantly enhance cognitive understanding of geometric structures.

Another study by Martín-Gutiérrez et al. investigated AR-based visualization tools for engineering education and concluded that immersive visualization technologies improve student comprehension of complex spatial structures [20]. Research by Fonseca et al. also demonstrated that AR-based learning systems help students better understand geometric transformations by allowing them to interact with three-dimensional models in real-time [21]. However, while these systems allow students to explore geometric objects interactively, they rarely provide mechanisms that explain spatial errors during the learning process.

Table 1 : Comparison of Existing Research Systems with the Proposed System

Feature / Criteria	AR Geometry Learning System [1]	Sketch2Model [6]	DeepSketch2Face [8]	Air-Writing System [11]	Gesture CNN Recognition [9]	AR Educational Interface [4]	AR STEM Learning System [14]	Sketch Recognition Model [29]	Mobile AR Education Platform [27]	Proposed System
AR-Based Visualization	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes
2D-to-3D Sketch Conversion	No	Yes	Yes	No	No	No	No	Yes	No	Yes
Mathematical Net Foldability Validation	No	No	No	No	No	No	No	No	No	Yes
Real-Time Stroke Order Monitoring	No	No	No	Yes	Partial	No	No	Partial	No	Yes
Trajectory-Based Recognition	No	No	No	Yes	Yes	No	No	Yes	No	Yes
Visual Scaffolding (Ghost Feedback)	No	No	No	No	No	No	No	No	No	Yes
Virtual Slicing Visualization	No	No	No	No	No	No	No	No	No	Yes
Mobile Optimization for Classroom Use	Partial	No	No	Partial	Partial	Yes	Yes	Partial	Yes	Yes
Integrated Geometry + Literacy Learning	No	No	No	No	No	No	No	No	No	Yes

1.3 Research Gap

Although Augmented Reality (AR) and Artificial Intelligence (AI) technologies have increasingly been applied in educational environments, many existing learning systems still fail to effectively support primary school students in developing strong spatial understanding of geometric concepts and foundational literacy skills. Traditional teaching methods rely heavily on static two-dimensional diagrams to explain three-dimensional geometric concepts such as nets and volumes, which makes it difficult for young learners to visualize how shapes exist and behave in real space. At the same time, students often struggle with mastering correct English letter stroke sequences and connecting visual objects with their corresponding vocabulary in engaging learning environments. As identified in the project topic assessment document, the overall research problem of this project can therefore be expressed as the following research question:

Research Problem (Main): How can a mobile-based AI and Augmented Reality (AR) system be designed to accurately convert student drawn 2D sketches into validated 3D geometric models, verify geometric net correctness, and simultaneously support English letter stroke guidance and vocabulary learning in a single low cost, real time interactive educational environment optimized for primary school learners?

Within this broader research problem, several limitations exist in current AR-based geometry learning systems. First, many applications focus mainly on visualizing predefined three-dimensional models rather than allowing students to create and validate their own geometric constructions. Second, most systems provide only binary feedback indicating whether a student's answer is correct or incorrect, which does not help learners understand the cause of their spatial mistakes. Third, existing educational tools rarely incorporate visual scaffolding techniques that guide students in correcting errors through direct visual comparison with the correct geometric structure. Additionally, most systems do not include volumetric slicing visualizations, which could help learners understand the internal structure of geometric solids and concepts such as fractional volumes. Furthermore, there is limited research exploring the integration of ghost overlay visualization techniques within mobile AR learning environments to assist students during geometric construction tasks.

Therefore, the specific research problem addressed in this component can be expressed as the following question:

Research Problem (Sub Component): How can adaptive visual scaffolding and virtual slicing techniques be integrated into a mobile AR geometry learning system to provide real-time visual explanations for spatial errors during geometric construction tasks?

To address this gap, this research proposes an Adaptive Scaffolding and Virtual Slicing framework that introduces transparent ghost overlay models for spatial guidance and an interactive slicing visualization module that allows learners to explore internal geometric structures. By combining AR visualization with adaptive visual feedback mechanisms, the proposed approach aims to improve spatial reasoning, enhance conceptual understanding, and provide more effective support for geometry learning among primary school students.

2. OBJECTIVE

2.1 Main Objective

The main objective of this research is to design and develop an integrated mobile-based Augmented Reality (AR) and Artificial Intelligence (AI) educational system that transforms traditional static two-dimensional learning into an interactive three-dimensional learning experience for primary school students. The system aims to accurately convert student-drawn 2D sketches into validated 3D geometric models, verify the correctness of geometric nets, and simultaneously support English letter stroke guidance and vocabulary learning within a single low-cost, real-time AR learning environment optimized for children aged 6–12.

2.2 Specific Objectives

To achieve the main objective, the research project is divided into four specialized components corresponding to the contributions of the project members.

- **2D-to-3D Geometry Validation** – To develop a computer vision-based recognition system capable of detecting hand-drawn geometric nets and mathematically validating whether they can form correct three-dimensional shapes before generating interactive 3D models.
- **Adaptive Scaffolding and Virtual Slicing** – To implement interactive visual feedback mechanisms that explain spatial errors using ghost overlay visualizations and volumetric slicing techniques within an augmented reality environment.
- **AI Air-Writing Trajectory Tracking** – To design a CNN-based recognition system that tracks and analyzes finger movement trajectories in three-dimensional space in order to monitor and correct English letter stroke order and writing direction.
- **Multisensory Phonics and Vocabulary Integration** – To develop an interactive learning module that connects sketches, air-writing, and pronunciation with animated 3D objects to reinforce vocabulary learning and phonics development.

This research proposal report focuses specifically on the **Adaptive Scaffolding and Virtual Slicing component** of the overall system. The objective of this component is to develop an interactive visual scaffolding mechanism that helps students understand spatial errors during geometric construction tasks. Instead of providing simple binary feedback indicating whether a student's answer is correct or incorrect, the system introduces ghost overlay visualizations, which display transparent reference models that guide learners toward the correct geometric structure. These overlays allow students to visually compare their constructions with the correct configuration and identify where spatial misalignment occurs. In addition to visual scaffolding, this component also introduces a virtual slicing visualization module that enables students to explore the internal structure of three-dimensional geometric objects. By slicing geometric solids into fractions such as one-half or one-third, the system provides an intuitive way for learners to understand concepts related to volume and internal spatial composition. Together, these features create a guided AR learning experience that improves spatial reasoning, supports conceptual understanding of geometry, and provides real-time corrective feedback during the learning process.

3. METHODOLOGY

Research Approach

This research follows a Design Science Research (DSR) methodology, which focuses on designing and evaluating technological artifacts that address real-world problems. The proposed system is developed as an interactive AR learning tool that integrates visualization, spatial analysis, and adaptive feedback mechanisms.

The research process includes the following stages:

1. Problem identification and requirement analysis
2. System design and architecture development
3. Implementation of AR visualization and scaffolding modules
4. Experimental evaluation with users
5. Performance analysis and system refinement

System Development Technologies

The proposed system will be implemented using the following technologies:

- **Unity 3D**

Unity is selected as the primary development platform due to its strong support for interactive 3D graphics, cross-platform deployment, and integration with AR development frameworks.

- **ARCore**

ARCore provides markerless augmented reality capabilities that enable virtual objects to be placed within real-world environments using mobile devices. ARCore supports plane detection, motion tracking, and environmental understanding, which are essential for AR-based learning applications.

- **C# Programming**

The system logic and AR interactions will be implemented using the C# programming language within the Unity development environment.

- **Blender**

Blender will be used to design and optimize 3D models used for geometric visualization and ghost overlay rendering.

Data Collection

Data for the evaluation of the proposed system will be collected through controlled user testing with primary school students.

The evaluation process will involve:

- Pre-test to assess baseline spatial reasoning ability
- Interaction with the AR learning system
- Post-test to measure improvement in conceptual understanding

User feedback will also be collected to evaluate usability, engagement, and learning effectiveness.

Ethical Considerations

Since the research involves children aged between 6 and 12 years, ethical approval will be obtained from the relevant institutional ethics committee. Parental consent will be obtained before conducting user studies, and all collected data will be anonymized to protect participant privacy.

Evaluation Metrics

The effectiveness of the proposed system will be evaluated using the following metrics:

- Learning improvement score (pre-test vs post-test results)
- Task completion accuracy
- Error correction time
- User engagement level
- System usability score (SUS)

4. HIGH-LEVEL SYSTEM ARCHITECTURE

Overview of the Proposed Solution

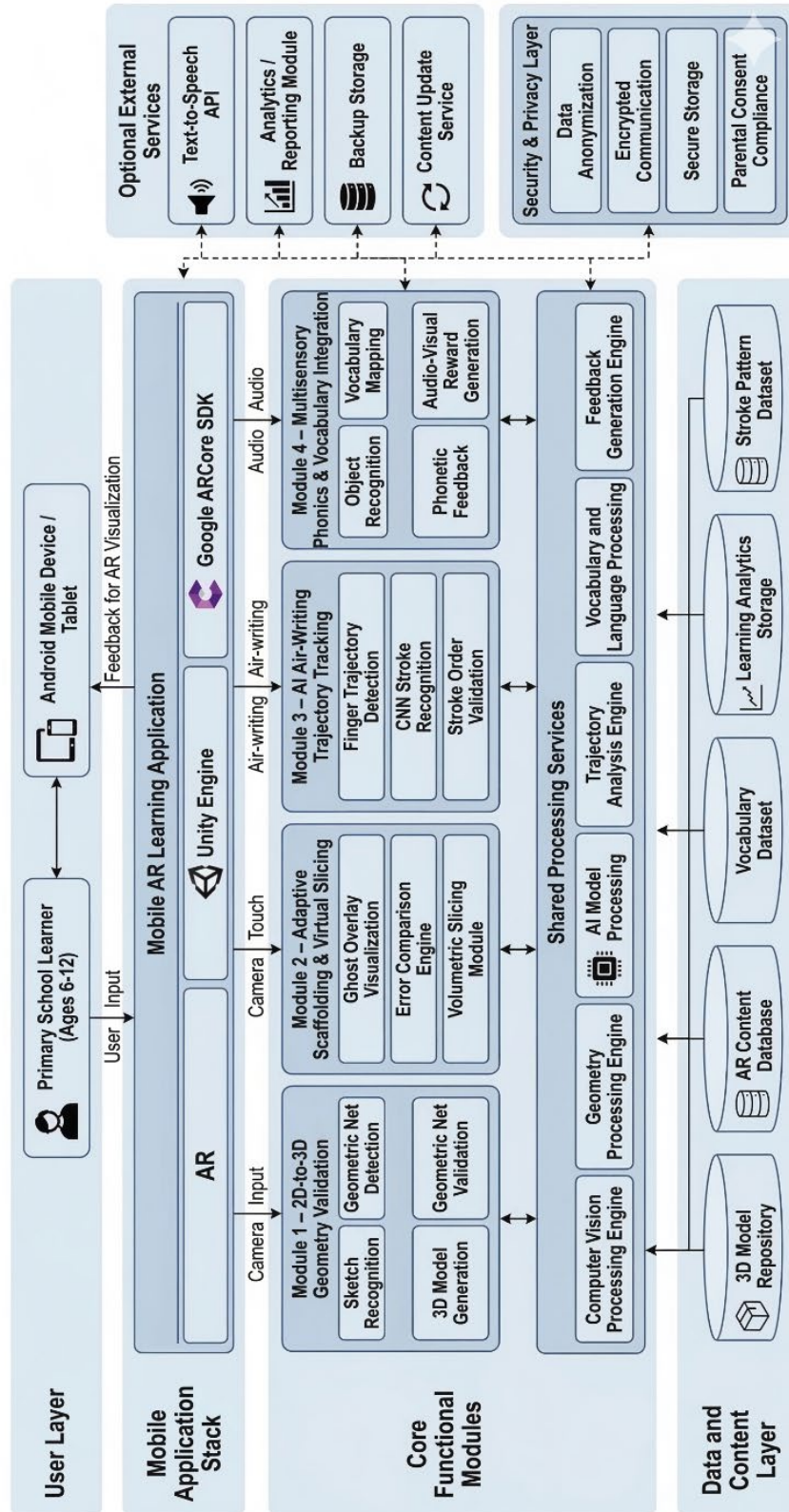


Figure 1 : High Level System Architecture

The proposed system is a mobile Augmented Reality (AR) educational platform designed to enhance spatial understanding and conceptual learning among primary school students. The system integrates Artificial Intelligence (AI), computer vision techniques, geometric validation algorithms, and augmented reality visualization to transform traditional static learning methods into an interactive educational experience. Through the use of mobile devices, students are able to draw geometric sketches, visualize them as three-dimensional objects, and receive immediate visual feedback that helps them understand spatial relationships and geometric structures.

At a high-level system architecture, the proposed solution consists of several interconnected modules that collectively perform input capture, geometric analysis, learning interaction, and visualization. The architecture follows a modular and layered design, where the mobile AR application communicates with processing modules responsible for sketch interpretation, spatial validation, learning feedback generation, and AR rendering. This design ensures scalability, flexibility, and maintainability while allowing different learning components to operate together within a single educational environment.

The core technologies used in the system include Unity 3D for application development and Google ARCore for markerless augmented reality tracking and spatial mapping. Unity enables the creation of interactive 3D educational environments, while ARCore allows virtual objects to be accurately positioned and manipulated within real-world environments using the mobile device camera and sensors. Together, these technologies support real-time interaction between the learner and the AR-based educational content.

The High-Level System Architecture of the proposed solution consists of several major modules that form a sequential processing pipeline:

- 1) **Input Acquisition Module** – Captures user input through the mobile device camera and touch interface.
- 2) **Sketch Processing Module** – Detects and interprets student-drawn geometric sketches using computer vision techniques.
- 3) **Geometric Validation Engine** – Evaluates whether the detected geometric nets can correctly form valid three-dimensional shapes.
- 4) **Adaptive Scaffolding Module** – Provides visual guidance by comparing student constructions with correct geometric configurations.
- 5) **Virtual Slicing Visualization Module** – Demonstrates internal structures of geometric solids by virtually slicing 3D models.
- 6) **AR Rendering Engine** – Displays validated 3D models and visual feedback within the real-world environment.
- 7) **Feedback and Interaction Module** – Provides real-time learning feedback and interactive guidance for students.

These modules work together to transform a student's hand-drawn sketch into an interactive AR learning experience. The system begins by capturing input, processes and validates geometric structures, and finally visualizes results through immersive AR

feedback. Within this overall architecture, the Adaptive Scaffolding Module represents the individual research component of this study. This component introduces an innovative visual guidance mechanism that assists learners in understanding spatial errors during geometric construction tasks. Instead of providing simple correct-or-incorrect feedback, the module generates ghost overlay visualizations, which display transparent reference models aligned with the correct geometric configuration. This allows students to directly compare their own constructions with the correct structure and identify spatial discrepancies.

Additionally, the Adaptive Scaffolding Module works together with the Virtual Slicing Visualization Module, enabling students to explore the internal structure of geometric solids by virtually slicing 3D models into fractional sections. This feature supports the understanding of concepts such as volume and fractional divisions, which are often difficult for young learners to visualize.

System Diagram of Components

The System Diagram of Components illustrates the high-level interactions between the major modules of the AR-based geometry learning system. The architecture follows a data processing pipeline, beginning with user input acquisition and ending with interactive visual feedback delivered through the AR interface.

The diagram represents the following key components:

- Input Acquisition Module
- Sketch Processing Module
- Geometric Validation Engine
- Adaptive Scaffolding Module
- Virtual Slicing Visualization Module
- AR Rendering Engine
- Feedback and Interaction Module

Each component performs a specific role within the system architecture, ensuring a continuous flow of information between input processing, geometric analysis, visualization, and feedback generation. The Adaptive Scaffolding Module is highlighted within the architecture, as it represents the primary contribution of this research. This module introduces an adaptive visual guidance mechanism that explains spatial errors through ghost overlay visualization, allowing learners to identify and correct mistakes in their geometric constructions. By integrating this module into the AR learning environment, the proposed system provides a more effective and intuitive approach to geometry education compared with existing AR-based learning systems.

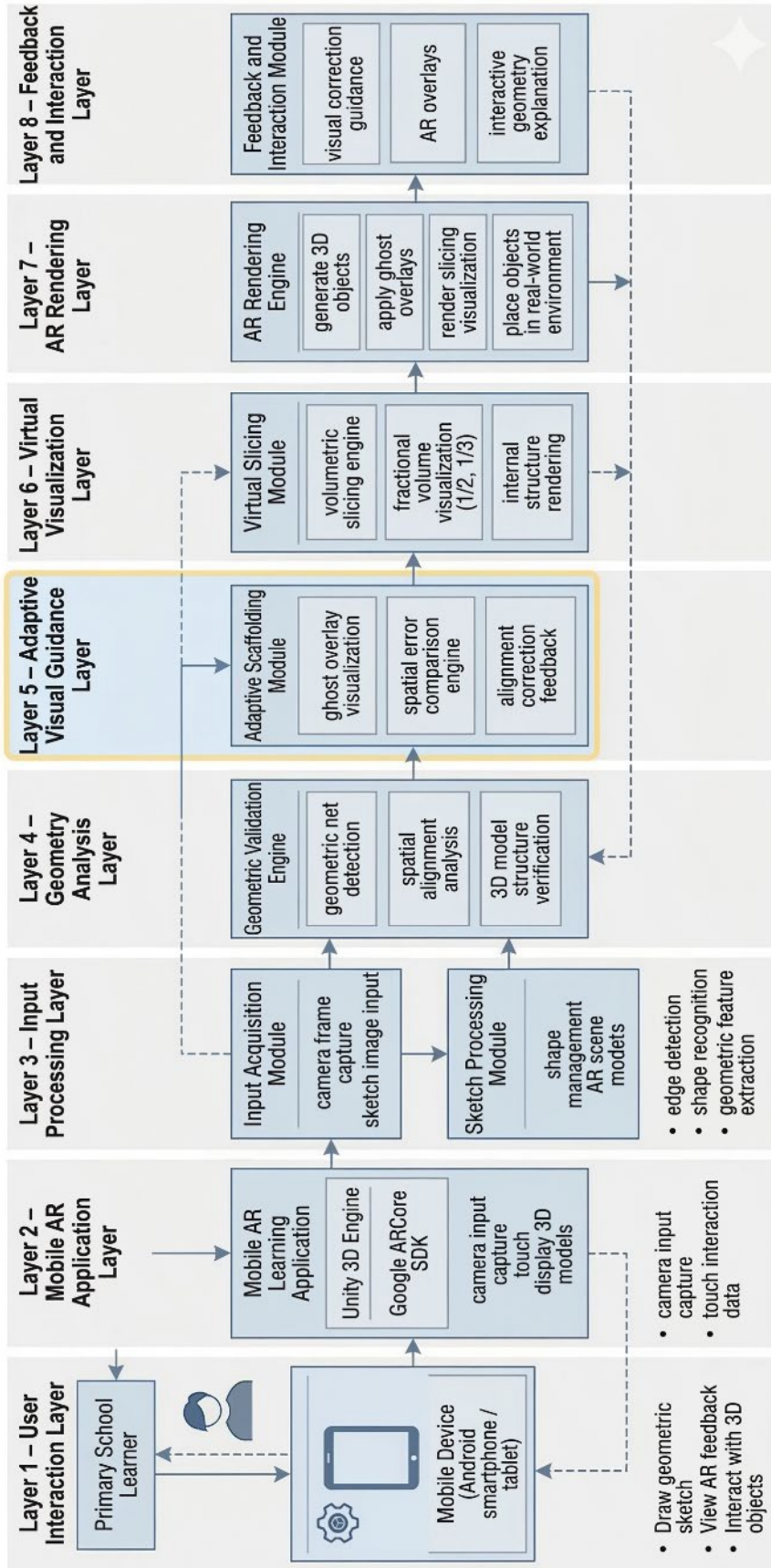


Figure 2 : High Level System Architecture for Individual Component

Individual Component and Its Parts

The Adaptive Scaffolding Module is the primary contribution of this research component. It is responsible for providing visual guidance to students when spatial errors are detected in geometric constructions.

This module consists of several subcomponents that work together to analyze student-generated models and generate corrective feedback.

- **Ghost Model Generator**

This component generates a reference 3D model representing the correct geometric structure. The model is displayed as a transparent overlay in the AR environment.

- **Visual Comparison Engine**

The visual comparison engine compares the student-generated model with the reference model and calculates spatial discrepancies between the two structures.

- **Error Evaluation Logic**

This component analyzes the geometric differences detected during comparison and identifies the specific spatial relationships that are incorrect.

- **Interactive Overlay Renderer**

The overlay renderer displays the ghost model in the AR environment using transparent rendering techniques, allowing students to visually compare their models with the correct configuration.

- **Adaptive Feedback Controller**

This component dynamically adjusts the feedback provided to the student based on the type of error detected, ensuring that guidance remains informative and easy to understand.

Together, these components enable the system to provide visual scaffolding rather than simple binary feedback, which significantly enhances conceptual understanding.

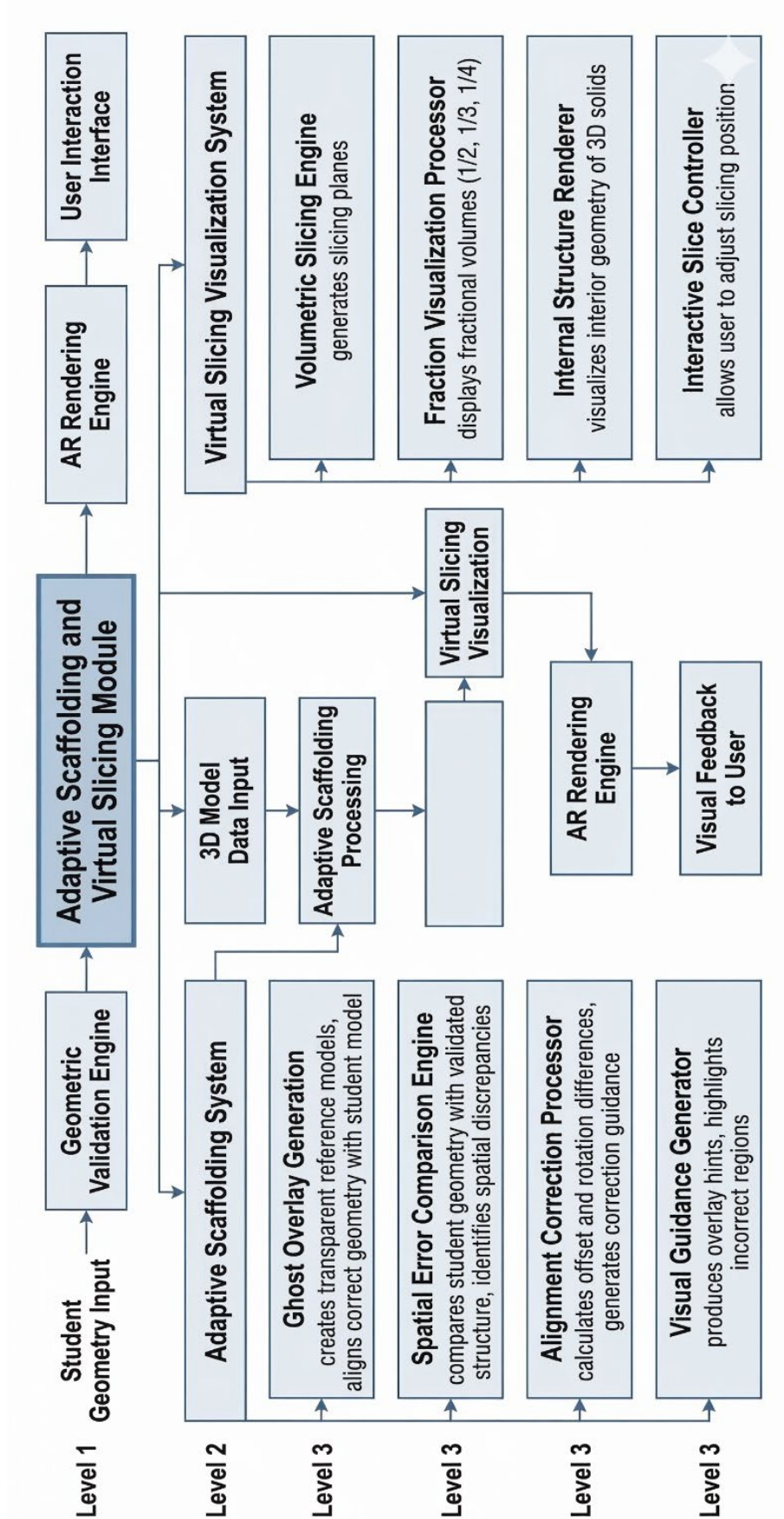


Figure 3 : Component Breakdown Diagram

Component Interactions

The modules in the proposed system interact sequentially to process user input and generate visual feedback.

1. The Input Acquisition Module captures sketches or geometric drawings using the mobile device camera.
2. The Sketch Processing Module extracts geometric features from the detected drawing and converts the structure into a digital representation.
3. The Geometric Validation Engine analyzes the structure to determine whether the geometric net can form a valid three-dimensional object.
4. If an error is detected, the Adaptive Scaffolding Module generates visual guidance through ghost overlays and comparison visualization.
5. The Virtual Slicing Visualization Module demonstrates geometric concepts such as volume fractions through interactive slicing of the generated model.
6. The AR Rendering Engine displays all visual elements within the augmented environment using Unity and ARCore.
7. Finally, the Feedback and Interaction Module presents visual cues and guidance that help students correct their spatial mistakes.

Data Flow Explanation

The data flow within the system follows a multi-stage processing pipeline:

Step 1 – User Input

Students draw a geometric net on paper or interact with the AR interface.

Step 2 – Image Capture

The mobile device camera captures the input using ARCore's tracking capabilities.

Step 3 – Sketch Analysis

The sketch processing module extracts geometric features and constructs a digital representation of the shape.

Step 4 – Geometric Validation

The validation engine evaluates whether the geometric net can form a valid three-dimensional object.

Step 5 – Scaffolding Activation

If the structure is invalid, the adaptive scaffolding module generates a ghost reference model.

Step 6 – Visualization

The AR rendering engine displays the student model and reference model simultaneously

Step 7 – Feedback

Visual guidance and interactive cues help the student identify and correct spatial errors.

This data flow ensures that feedback is delivered in real time, allowing students to learn through experimentation and visual exploration.

Scalability Considerations

The system is designed to support scalability in several ways:

- The modular architecture allows new learning modules to be integrated without modifying the core system.
- The system can support additional geometric shapes and educational content through database expansion.
- Cloud integration can be implemented in the future to support collaborative learning environments.

The use of Unity and ARCore also enables cross-device deployment, allowing the system to run on a wide range of Android devices that support AR functionality.

Security Considerations

Although the system primarily functions as an educational tool, several security considerations must be addressed.

User data collected during evaluation studies will be anonymized to ensure privacy protection. Additionally, all stored data will be secured using encrypted storage mechanisms to prevent unauthorized access.

The system will also ensure that no personal identifiable information (PII) is stored without consent, particularly because the evaluation involves primary school students.

5. USER REQUIREMENTS

Stakeholders

The primary stakeholders of the system include:

- Primary school students
- Teachers
- Educational institutions
- Parents

Functional Requirements (FR)

FR1 – The system shall detect student-drawn geometric nets using the mobile device.

FR2 – The system shall convert detected sketches into three-dimensional geometric models.

FR3 – The system shall validate whether a geometric net can fold into a valid 3D structure.

FR4 – The system shall display ghost overlay models when spatial errors are detected.

FR5 – The system shall allow users to visualize geometric slicing of objects.

FR6 – The system shall provide visual feedback to guide students in correcting mistakes.

FR7 – The system shall render interactive 3D models using AR technology.

Non-Functional Requirements

- **Performance**

The system should process geometric recognition and rendering within two seconds.

- **Usability**

The interface must be simple enough for children aged 6-12 to use without supervision.

- **Compatibility**

The system must run on Android devices supporting ARCore.

- **Security**

All user data collected during evaluation will be anonymized.

6. COMMERCIALIZATION PLAN

Target Market

The proposed AR-based geometry learning system is designed for the education technology (EdTech) market, particularly focusing on primary education institutions and digital learning platforms.

The primary target market segments include:

- Primary schools implementing digital learning tools
- Private tutoring institutes specializing in mathematics education
- Educational technology companies developing interactive learning solutions
- Parents seeking supplementary learning tools for children
- Online learning platforms integrating interactive educational content

The system addresses a growing demand for interactive and immersive learning tools, particularly in STEM education. With the increasing adoption of mobile devices in classrooms, AR-based educational technologies have strong commercial potential.

Customer Personas

Table 2: Customer Personas

Persona	Description	Needs	Pain Points	Value from Proposed System
Primary School Teacher	Mathematics teacher teaching geometry concepts to students aged 6–12	Interactive teaching tools for explaining spatial concepts	Students struggle to understand 3D structures using textbooks	AR visualization helps explain geometric nets and volume clearly
School Administrator	Decision maker responsible for selecting educational technologies	Cost-effective digital learning platforms	Limited budget and lack of interactive teaching tools	Affordable mobile-based AR learning solution
Parent of Primary School Student	Parent supporting child's education at home	Engaging learning tools for children	Children lose interest in traditional learning methods	Gamified AR learning improves engagement and understanding
Private Tutor	Individual or small tutoring center teaching mathematics	Tools to demonstrate complex concepts quickly	Difficulty explaining spatial geometry concepts	AR models provide visual explanation of geometric structures
EdTech Platform Developer	Company developing educational applications	Innovative learning technologies to integrate into products	Need unique learning features to differentiate products	Integration of AR learning modules enhances platform capability

Value Proposition

The proposed system offers several key benefits that distinguish it from traditional learning tools and existing AR educational applications.

The primary value proposition includes:

- Interactive learning experience through AR visualization of geometric models
- Adaptive visual scaffolding that explains spatial errors instead of simple binary feedback
- Virtual slicing visualization that helps students understand geometric volume and fractions
- Mobile accessibility, enabling learning through commonly available smartphones

By combining these features, the system provides a more effective learning experience compared to traditional textbook-based geometry education

Revenue Model

The proposed system can be commercialized using multiple revenue streams.

- Educational Software Licensing

Schools can purchase annual licenses to use the AR learning platform within classrooms.

- Mobile Application Subscription

Parents can subscribe to a mobile learning application that provides interactive geometry lessons.

- Platform Integration

Educational technology companies can license the AR learning module for integration into existing e-learning platforms.

- Premium Model

A basic version of the application could be provided for free, while advanced learning modules and analytics tools are available through paid upgrades.

Cost Estimation

Table 3 : Estimated Development Costs

Cost Category	Description	Estimated Cost (LKR)
Development Hardware	AR-capable mobile device	60,000
Software Tools	Unity development tools and plugins	25,000
Cloud Services	Data storage and analytics	25,000
Miscellaneous Research Expenses	Documentation and research materials	30,000

Total Estimated Cost: LKR 140,000

Pricing Strategy

The pricing strategy for the proposed system will follow a **tiered pricing model** to ensure affordability for educational institutions while generating sustainable revenue.

Table 4 : Proposed Pricing Structure

Product	Pricing Model
Mobile Learning Application	Freemium model
Premium Learning Modules	LKR 1,500 per year subscription
School License	LKR 50,000 annual institutional license
EdTech Integration License	Negotiated B2B licensing model

Competitive Advantage

Table 5 : Competitive Advantage

Feature	Existing Systems	Proposed System
AR Visualization	Limited	Yes
Sketch-to-3D Interaction	Rare	Yes
Visual Scaffolding Feedback	No	Yes
Virtual Slicing Visualization	No	Yes
Mobile AR Learning Platform	Partial	Yes

Intellectual Property Considerations

The proposed system introduces novel features that may be eligible for intellectual property protection.

Potential IP protection includes:

- Software copyright protection for the AR learning application
- Algorithmic protection for the visual scaffolding and geometric validation modules
- Trademark registration for the product name and branding

If the system demonstrates commercial success, further protection such as patents for interactive AR learning techniques may be explored.

7. BUDGET AND JUSTIFICATION

Hardware Costs

The primary hardware requirement for the project is an AR-capable mobile device or tablet that supports ARCore. This device will be used to test the mobile augmented reality application and evaluate system performance under real-world conditions.

Table 6 : Hardware Cost Estimation

Item	Description	Quantity	Unit Cost (LKR)	Total Cost (LKR)	Justification
AR-Compatible Smartphone	Android device supporting ARCore for application testing	1	60,000	60,000	Required to test AR tracking, camera input, and rendering performance
External Storage	Portable SSD or hard drive for storing research datasets and assets	1	20,000	20,000	Required for storing 3D models, datasets, and project files

Total Hardware Cost: LKR 80,000

Software Licenses

Most software tools used in the development of the system are available through free academic or open-source licenses, which significantly reduces development costs.

Table 7 : Software Cost Estimation

Software	Purpose	License Type	Estimated Cost (LKR)	Justification
Unity 3D	AR application development	License	25 000	Used to build the AR learning environment
Blender	3D modeling and asset creation	Open Source	0	Used to design geometric models
Visual Studio	Programming and debugging	Free	0	Used for C# development in Unity
ARCore SDK	Markerless AR functionality	Free	0	Required for AR environment tracking

Total Software Cost: LKR 25,000

Cloud Services

Cloud infrastructure may be required to store evaluation data and backup research materials.

Table 8 : Cloud Service Cost Estimation

Service	Description	Estimated Cost (LKR)	Justification
Cloud Storage	Storage for research data and testing results	15,000	Required to store datasets and evaluation results
Backup Services	Backup of research files and system assets	10,000	Prevents loss of important research data

Total Cloud Service Cost: LKR 25,000

Miscellaneous Research Expenses

Certain additional costs may occur during the evaluation and testing phases of the research.

Table 9 : Miscellaneous Expenses

Item	Description	Estimated Cost (LKR)	Justification
Printing and Documentation	Printing of evaluation materials and reports	5,000	Required for research documentation
User Testing Materials	Materials required for usability testing with students	25,000	Supports evaluation phase

Total Miscellaneous Cost: LKR 30,000

Total Estimated Budget

Table 10 : Project Budget Summary

Cost Category	Estimated Cost (LKR)
Hardware	60,000
Software	25,000
Cloud Services	25,000
Miscellaneous	30,000

Total Estimated Project Cost: LKR 140,000

Budget Justification

The budget allocated for this project reflects the minimal resources required to successfully develop and evaluate the AR-based learning system.

Since Researcher already possess a suitable development laptop and performs the system development independently, no additional costs are allocated for development hardware or human labor. This significantly reduces the overall project cost.

The primary expense is the acquisition of an AR-compatible mobile device or tablet, which is essential for testing the application in a real-world augmented reality environment. Cloud storage services are included to manage research datasets and system assets, while miscellaneous expenses support the evaluation and documentation phases of the research.

Overall, the estimated budget demonstrates that the proposed system can be developed using relatively low-cost resources, making it feasible for future deployment in educational institutions.

8. WORK BREAKDOWN STRUCTURE (WBS)

Table 11 : Work breakdown structure

Phase	Task
Phase 1	Literature review and research analysis
Phase 2	System design and architecture development
Phase 3	AR environment setup using Unity and ARCore
Phase 4	Implementation of ghost overlay module
Phase 5	Implementation of virtual slicing visualization
Phase 6	System integration and testing
Phase 7	User evaluation and data analysis
Phase 8	Final report preparation

9. GANTT CHART

Table 12 : Gantt Chart

Phase	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Literature Review & Benchmarking								
Requirement Analysis & Problem Definition								
System Architecture Design								
AR Environment Setup (Unity + ARCore)								
Adaptive Scaffolding Module Development								
Virtual Slicing Visualization Development								
System Integration & Testing								
User Evaluation & Data Collection								
Data Analysis & Performance Evaluation								
Final Report Writing & Documentation								

10. REFERENCES

- [1] A. I. e. al., "Experimenting with electromagnetism using augmented reality," in *Proc. IEEE EDUCON*, 2014.
- [2] I. Radu, "Augmented reality in education: A meta-review," in *Proc. IEEE ISMAR*, 2012.
- [3] H. Kaufmann and D. Schmalstieg, "Mathematics and geometry education with collaborative AR," in *Proc. ACM VRST*, 2003.
- [4] Z. H. e. al., "DeepSketch2Face: Sketch-based 3D face modeling," in *Proc. Eurographics Symposium on Geometry Processing*, 2018.
- [5] P. M. e. al., "Hand gesture recognition with 3D convolutional neural networks," in *Proc. IEEE CVPR Workshops*, 2015.
- [6] X. C. e. al., "Online handwritten text recognition using recurrent neural networks," in *Proc. ICDAR*, 2015.
- [7] K. B. e. al., "Augmented reality for STEM learning,," in *Proc. IEEE VR*, 2013.
- [8] M. Dünser and E. Hornecker, "Lessons from AR educational interfaces," in *Proc. IEEE ISMAR*, 2007.
- [9] D. W. e. al., "The role of tutoring in problem solving," in *Proc. IEEE ITS Conference*, 1976.
- [10] M. C. e. al., "Intelligent tutoring systems with adaptive feedback," in *Proc. AIED Conference*, 2011.
- [11] C. Dede, "Immersive learning environments," in *Proc. IEEE VR*, 2009.
- [12] M. J.-G. e. al., "mbodied learning through AR," in *Proc. IEEE VR*, 2014.

- [13] J. M.-G. e. al., "Augmented reality in engineering education," in *Proc. IEEE EDUCON*, 2015.
- [14] D. F. e. al., "AR visualization for spatial understanding," in *Proc. IEEE EDUCON*, 2014.
- [15] Y. L. e. al., "Real-time gesture recognition," in *Proc. IEEE CVPR Workshops*, 2016.
- [16] S. M. e. al., "Hand gesture recognition using CNN," in *Proc. IEEE ICIP*, 2017.
- [17] T. K. e. al., "Markerless augmented reality tracking," in *Proc. IEEE ISMAR*, 2013.
- [18] L. Y. e. al., "Sketch-based modeling using deep learning," in *Proc. IEEE ICCV Workshops*, 2017.
- [19] J. L. e. al., "Interactive AR learning systems," in *Proc. IEEE VR*, 2016.
- [20] H. P. e. al., "Mobile AR for education," in *Proc. IEEE ISMAR Workshops*, 2018.
- [21] C. C. e. al., "AR visualization in STEM education," in *Proc. IEEE EDUCON*, 2019.
- [22] R. Z. e. al., "Deep learning for sketch recognition," in *Proc. IEEE CVPR Workshops*, 2018.
- [23] K. N. e. al., "Augmented reality interaction techniques," in *Proc. IEEE VR*, 2020.
- [24] M. D. e. al., "An educational augmented reality game," in *Proc. IEEE ISMAR*, 2007.
- [25] B. Shelton and N. Hedley, "Using augmented reality for teaching Earth-Sun relationships," in *Proc. IEEE VR*, 2002.
- [26] W. W. e. al., "Sketch2Model: Sketch-based 3D modeling," in *Proc. IEEE VR*, 2011.
- [27] P. X. e. al., "Deep learning for sketch-based 3D shape retrieval," in *Proc. IEEE CVPR Workshops*, 2015.

- [28] C. A. e. al., "AirWriting: Hands-free mobile text input," in *Proc. ACM ICMI*, 2012.
- [29] M. B. e. al., "A survey of augmented reality,," in *Proc. IEEE VR*, 2015.
- [30] R. A. e. al., "Recent advances in augmented reality," in *Proc. IEEE Computer Graphics*, 2001.

11. APPENDICES

Appendix A – Preliminary User Interface Mockups

This appendix includes the initial interface concepts of the proposed mobile application. The mockups illustrate the main student interaction screens, including:

- Home screen of the AR learning application
- Geometry sketch capture interface
- Ghost overlay feedback screen
- Virtual slicing visualization screen
- Result and correction feedback interface

These mockups help demonstrate the intended interaction flow and usability of the system.

Appendix B – System Diagrams

This appendix contains the diagrams used to explain the technical design of the proposed system. These include:

- High-Level System Architecture Diagram
- System Diagram of Components
- Individual Component and Its Parts
- Visual Methodology Diagram
- Research Gap Diagram

These diagrams provide a clearer understanding of the system structure, workflow, and novelty of the proposed research component.

Appendix C – Risk Analysis

This appendix summarizes the possible risks related to the development and evaluation of the system.

Technical Risks

- AR tracking instability on low-end devices
- Difficulty in rendering overlays accurately in real time
- Performance issues when handling multiple 3D visualizations

Research Risks

- Limited access to student participants for testing
- Delays in collecting evaluation data
- Difficulty in measuring learning improvement within a short testing period

Mitigation Strategies

- Use ARCore-compatible devices for stable testing
- Optimize 3D assets and rendering performance
- Prepare simplified testing sessions and backup evaluation plans

Appendix D – Ethical Considerations and Participant Materials

This appendix includes materials relevant to ethical review and participant involvement.

Included Items

- Parent/guardian consent form draft
- Participant information sheet
- Assent form for child participants
- Data privacy and anonymization statement

Since the proposed system is intended for primary school students, ethical handling of participant data is important during the evaluation stage.