ScilenceAR: A Mobile Augmented Reality Platform for Interactive Science Learning

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Abstract — Augmented Reality (AR) has emerged as a powerful technology for enhancing interactive learning in STEM disciplines. Traditional science education relies heavily on static two-dimensional visualizations, limiting students' ability to grasp complex concepts. This paper presents ScilenceAR, a mobile AR platform designed to improve conceptual understanding through immersive 3D simulations anchored in the physical classroom. Developed using Unity 3D, AR Foundation, ARCore, and Firebase, the application covers Physics, Chemistry, and Biology. It supports interactive features such as real-time model manipulation via touch gestures, integrated video learning, downloadable notes, and progress tracking. Experimental evaluation with 55 users demonstrates statistically improved engagement (87.5%), better visualization clarity (91.2%), and enhanced conceptual retention compared to conventional methods. A System Usability Scale (SUS) score of 82.4 confirms high usability, indicating that lightweight, markerless AR plat- forms effectively bridge the gap between theoretical knowledge and practical understanding.

Keywords: Augmented Reality, ARCore, Science Education, Mobile Learning, Gamification, Unity 3D, Firebase

I. Introduction

Augmented Reality (AR) is transforming modern education by seamlessly integrating digital content with the physical world. Unlike traditional teaching methods dependent on textbooks, AR empowers students to visualize, manipulate, and interact with complex concepts in real time, fostering deeper cognitive engagement and improved knowledge retention [3, 4].

In science education, students frequently encounter difficulties understanding abstract topics such as Newtonian motion or molecular interactions. Conventional methods lack interactivity and spatial fidelity, leading to passive learning. Research demonstrates that experiential and visualization-driven instruction improves both short-term comprehension and long-term recall [1]. Mobile platforms have become the most accessible delivery medium for AR content, presenting an economically viable alternative to expensive laboratory equipment or dedicated head-mounted displays [6].

To address these challenges, this paper proposes ScilenceAR, an AR-based mobile application designed to en- hance science learning. The application focuses on three STEM domains: Physics, Chemistry, and Biology. It integrates real-time AR visualization, multimedia content, gesture-based interaction, and user progress tracking. The system leverages ARCore-based plane detection to place virtual 3D objects on real-world surfaces without requiring printed markers.

The key contributions of this work are:

– Design of a markerless, mobile AR learning platform covering Physics, Chemistry, and Biology.
– Integration of interactive 3D simulations combined with multimedia content.
– Implementation of cloud-based user authentication and personalized progress tracking via Firebase.
– Empirical evaluation demonstrating improved conceptual retention relative to traditional instruction.

II. Literature Review

Recent advancements in AR and mobile computing have significantly influenced educational methodologies. This section reviews key works informing ScilenceAR's design.

A. AR in STEM and Cultural Environments

Paat et al. [1] developed an AR-based learning tool for plant cultivation, demonstrating that domain-specific AR applications effectively support learners lacking access to physical specimens. Their study reported a 34.7% knowledge gain. Similarly, Huang et al. [2] proposed an extended reality (XR) framework for virtual museums. Their principles of spatial anchoring and real-world integration directly inform the surface-detection design of ScilenceAR.

B. Mobile AR and Personalized Gamification

Criollo-C et al. [3] conducted a controlled study on Mo- bile Augmented Reality (MAR) in higher education, showing that students using MAR scored 18% higher on post- assessments. Device compatibility was identified as a key adoption factor, motivating ScilenceAR's performance optimization strategy. Furthermore, Ristianto et al. [4] investigated personalized gamification, reporting significant improvements in intrinsic motivation. These findings inspired the inclusion of progress tracking and achievement indica- tors in ScilenceAR.

C. Interactive AR Platforms

Ba˘lu¸toiu et al. [5] presented TeachAR, an interactive AR platform for classroom collaboration, which separated con- tent management from AR rendering—a concept adapted into ScilenceAR's backend. Liu et al. [6] introduced Ev- erywhereAR, emphasizing context-awareness and flexible content placement, which guided ScilenceAR's adaptive surface-detection pipeline.

Despite these advancements, cross-domain, lightweight, markerless AR platforms that integrate user management and multimedia within a single mobile app remain scarce. ScilenceAR addresses this gap.

III. PROPOSED SYSTEM

A. System Overview

ScilenceAR provides an immersive learning experience using markerless plane detection to anchor 3D models onto real-world surfaces. As illustrated in Fig. 1, the system bridges student interactions with robust cloud backend ser- vices.

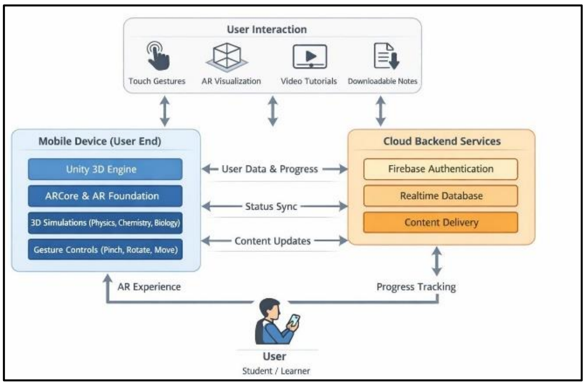

Fig. 1: ScilenceAR Use Case and Firebase Cloud Integration Architecture.

B. *Architectural Modules*

The architecture consists of four major modules:

- User Module: Manages registration, login, and profile management through Firebase Authentication.
- Subject Module: Categorized navigation for Physics, Chemistry, and Biology.
- Content Module: Delivers multimedia resources including instructional videos and PDF notes.
- AR Simulation Module: Handles rendering and interaction using Unity AR Foundation and ARCore.

C. *Data Flow and Integration*

The client-side Unity application communicates with Firebase for authentication and data persistence (Fig. 2). AR session data is managed locally to minimize latency, while user progress and notes access history synchronize to the Firebase Realtime Database.

IV. METHODOLOGY

Development followed an iterative, usercentered agile methodology.

Phase 1 & 2 (Requirement Analysis & Design): Requirements were gathered via interviews with science teachers and students. The architecture adopts a layered design separating user management, content delivery, and AR simulation. UI wireframes were validated with student proto- types.

Phase 3 & 4 (Implementation & Testing): The app was developed in Unity 3D with AR Foundation and AR- Core. 3D models were created in Blender and optimized for mobile. Testing was conducted across six Android devices to evaluate frame rate, detection latency, and Firebase synchronization.

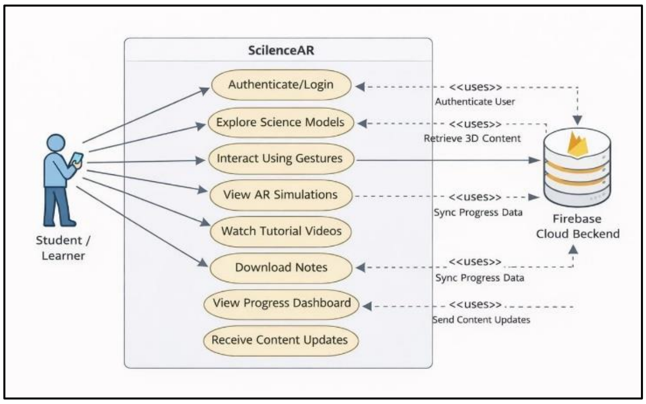

Fig. 2: Detailed Component and Interaction Diagram linking the Mobile Device with Cloud Backend Services.

Phase 5 (Evaluation): Evaluated with 55 participants who completed learning sessions, a 10-question assessment, and a System Usability Scale (SUS) questionnaire.

V. IMPLEMENTATION

A. *Technology Stack*

ScilenceAR utilizes Unity 3D, AR Foundation, and AR- Core for the frontend AR experience, programmed in C#. Firebase handles backend authentication and the realtime database.

B. *Simulation Modules & UI*

The Physics Module includes Newton's Laws, gravity, and interactive electric circuits. The Chemistry Module features Boyle's Law, states of matter, and a 3D periodic ta- ble. The Biology Module contains a detailed human heart, cell structures, and a photosynthesis simulation.

The UI features bottom-navigation for subject selection. Users place models via a guided surface-scanning screen and interact using pinch-to-scale, rotation, and drag gestures.

C. *Performance Optimization*

To ensure stability on mid-range hardware, strategies included polygon reduction (under 15,000 triangles per model), texture atlasing, and LOD configurations. This achieved sustained frame rates of 30–55 FPS across test de- vices.

VI. RESULTS AND DISCUSSION

A. *Learning Outcome Assessment*

Evaluation included 40 students divided into an AR- based experimental group (n = 22) and a textbook-based control group (n = 18). Post-session assessments (Table I) show the AR group achieved a mean knowledge gain of

B. *System Usability & Engagement*

The mean SUS score was 82.4, falling in the "Excellent" category. As detailed in Table II, 88% of users reported high engagement, and 64% voluntarily repeated simulations, indicating strong intrinsic motivation.

Metric	Value
Reported high engagement	88%
Found visualization clearer than textbooks	91%
Would recommend the app to peers	89%

Repeated a simulation voluntarily	64%

Table II: User Engagement Metrics (AR Group)

C. Performance Limitations

Performance testing confirmed stable frame rates on high-end (54.3 FPS) and mid-range (41.7 FPS) devices. However, low-end devices experienced occasional frame drops and a 2.1% crash rate. Additionally, AR detection requires adequate ambient lighting, limiting use in darker environments.

VII. CONCLUSION

ScilenceAR successfully demonstrates an augmented reality-based mobile platform that enhances science education through interactive, markerless 3D simulations. Evaluation with 55 participants yielded a learning gain of 37.3%, an Excellent usability score of 82.4, and over 87% engagement. These results confirm that mobile AR can effectively bridge the gap between theoretical knowledge and practical understanding. Future work will focus on expanding the content library to new subjects, integrating AI-driven adaptive learning pathways to personalize simulation difficulty, developing multi-user collaborative sessions, and improving low-end device performance through cloud-based rendering strategies.

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