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Neuronex: An Immersive Learning Experience Using Augmented Reality

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Abstract— Augmented Reality (AR) technology has emerged as a powerful tool in education, offering immersive and interactive learning experiences. This study presents Neuron-X, an e-learning application designed to bridge the gap between traditional instructional methods and modern, technology-enhanced education. The application integrates 3D models created in Blender with AR functionalities developed in Unity to visualize and interact with digital content in real-world contexts. Through interactive 3D models, diagrams, and simulations, Neuron-X aims to simplify complex concepts, promote active engagement, and improve knowledge retention among middle school students. The system's flexibility allows it to be applied across multiple subject areas, making it suitable for both educators and learners. By incorporating AR into the learning process, this research seeks to enhance student engagement, support diverse learning needs, and demonstrate the potential of AR-based tools in improving academic performance.

Keywords — Augmented Reality, e-learning, engagement, immersive, interactive, retention, technology – enhanced.

I. Introduction

Augmented Reality (AR) is a rapidly evolving technology that integrates virtual content into real-world environments, offering interactive and immersive learning experiences. Traditional educational methods, such as textbooks and lectures, often fail to engage students, particularly those with learning challenges. AR provides a dynamic alternative, allowing students to visualize abstract concepts and interact with them in real time. In this paper, we present Neuron-X, an AR-based e-learning platform designed to improve education for students with various learning needs, especially in Nepal.

A. *Background Theory*

Augmented Reality (AR) is an emerging technology that integrates digital elements such as 3D models, text, audio, and video into real-world environments, creating interactive and immersive user experiences. Unlike Virtual Reality (VR), which immerses users in entirely virtual settings, AR enhances real-world interactions through the overlay of digital content. Its implementation relies on cameras, sensors, and advanced software, making it applicable across various domains, including education, healthcare, and entertainment.

In the educational context, AR has transformed traditional learning by promoting engagement, visualization, and interactivity. Conventional teaching methods—often limited to textbooks and lectures—may not adequately address diverse learning styles. AR enables learners to visualize abstract concepts, manipulate virtual objects, and explore complex subjects in an intuitive manner. This multisensory learning approach supports visual, auditory, and kinaesthetic learners, while also benefiting students with conditions such as ADHD or Autism Spectrum disorder by maintaining focus and enhancing comprehension.

In Nepal, AR has significant potential to address educational disparities caused by geographic and infrastructural challenges. By leveraging mobile-based AR applications, students in remote areas can access high-quality learning materials, fostering inclusivity and equal opportunities. Additionally, AR can play a vital role in preserving Nepal's cultural heritage by creating interactive experiences that promote cultural awareness and appreciation.

Overall, AR's adaptability and accessibility make it a powerful educational tool. With adequate infrastructure, teacher training, and content development, AR can revolutionize Nepal's education system by enhancing engagement, improving learning outcomes, and supporting equitable access to quality education.

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B. *Problem Statement*

In Nepal, traditional education methods often fail to engage students, particularly those with diverse learning needs. Conventional approaches, relying mainly on lectures and videos, struggle to maintain attention and interest, especially as students' attention spans are becoming shorter in the digital age. This challenge is amplified for students with learning differences, who require more interactive and personalized learning experiences. Traditional methods fail to foster hands-on learning, critical thinking, and curiosity, which are essential for student success.

C. *Objective*

The objective of this project/ research is to develop an AR-based educational platform:

- To engage students with different learning capabilities (like ADHD, ASD, etc.) by providing a visual/ interactive and flexible approach to learning.

D. *Scopes and Application*

Neuron-X is designed to be adaptable to various subject areas, including mathematics, science, and social studies. The application provides students with an immersive environment to learn through visual and interactive methods. It is particularly suited for use in Nepal, where access to quality education and resources is limited in rural areas. The platform can be implemented on smartphones, allowing students from various backgrounds to benefit from augmented learning.

II. Literature review

Augmented Reality (AR) has gained significant attention as a transformative tool in education, enhancing engagement and interaction by integrating virtual objects into real-world environments. Research has demonstrated that AR improves student retention and comprehension, particularly for abstract concepts that are difficult to visualize. For example, Azuma et al. [1] showed that AR enhances user interaction with the real world by seamlessly integrating 3D virtual objects, creating more immersive learning experiences. Additionally, Billinghurst [2] emphasized that AR engages multiple sensory channels—visual, auditory, and haptic—allowing for a more comprehensive and interactive learning environment. Several studies have explored AR's effectiveness in teaching scientific concepts, such as Shelton and Hedley [7], who found that AR helps students better understand complex topics like the earth-sun relationship by allowing them to interact with simulations of planetary motion. Similarly, Garzón et al. [3] highlighted AR's adaptability across different age groups and learning settings, noting that it enhances motivation, collaboration, and problem-solving skills.

In addition to its success in classroom learning, AR has proven useful in real-world applications, such as decision-making and career guidance. For instance, Hermawan and Mochamad [4] developed an AR application that helps students visualize 3D models of campuses, aiding in their decision-making process when choosing schools. Furthermore, AR has shown great promise in vocational and experiential learning. Wojciechowski and Cellary [8] demonstrated how AR can simulate professional tasks in vocational education, reducing the learning curve for skill acquisition. However, there are challenges, such as technological limitations and the need for instructor training, as identified by Radianti et al. [6], which must be addressed to fully integrate AR into educational systems. Despite these challenges, studies like those of Ibáñez and Delgado-Kloos [5] suggest that AR's integration with gamified learning environments can increase motivation and create personalized learning experiences, making it a powerful tool for enhancing modern pedagogy.

A. Existing Systems

Several educational platforms, including Assemblr Edu, Brilliant, Arloon Geometry, and Merge Edu, use Augmented Reality (AR) to enhance STEM learning by making abstract concepts more interactive. Assemblr Edu enables the creation and exploration of 3D content, while Brilliant focuses on problem-solving and critical thinking. Arloon Geometry allows interaction with 3D geometric shapes to improve spatial understanding, and Merge Edu uses the Merge Cube to bring science concepts to life in a hands-on way. Despite the advancements these platforms offer, they face significant limitations. Most systems fail to cater to a wide range of learning capabilities, often missing personalized, adaptive experiences for learners with diverse needs. Additionally, the reliance on local storage for large 3D models poses challenges for devices with limited space, leading to performance issues such as slowdowns and crashes. Furthermore, these platforms often require stable internet connectivity, which can be problematic in areas with unreliable or poor internet access, limiting their accessibility for a global audience.

III. Methodology

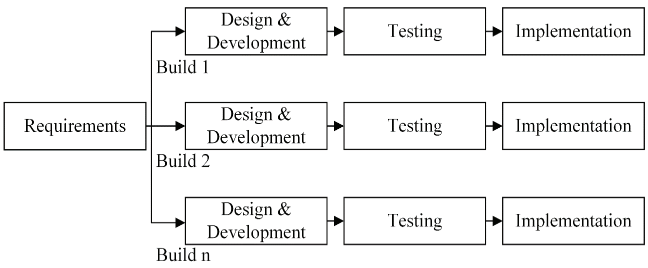

Fig. 1 Incremental Model

The development of our AR application follows the incremental model, a methodology that emphasizes the gradual building of the system through smaller, manageable modules. In this model, each module is developed independently, starting with detailed requirement analysis, followed by design, development, testing, and implementation. The process is iterative, allowing for continuous refinement and improvement. Each module is released separately, contributing new features or enhancements to the system. This approach ensures that the development process remains focused, flexible, and manageable, with clear milestones and regular feedback loops. The incremental model is well-suited for our project, allowing for a structured yet adaptable development cycle that ensures each phase of the application meets the required standards and integrates smoothly with previous increments.

In the Requirement Phase, the project's core objectives are established, including functional requirements for the AR system such as object recognition, real-time tracking, and platform compatibility. A feasibility study evaluates both technical and financial aspects to ensure the project's viability. The Design and Development Phase follows, where the system architecture is created, and each module is developed incrementally. This phase involves selecting appropriate AR frameworks, defining integration strategies, and ensuring scalability and real-time performance. Once a module is developed, it undergoes a thorough Testing Phase, which includes unit, integration, and user acceptance testing to identify and address any defects. Finally, in the Implementation Phase, tested modules are integrated into the overall system and deployed incrementally, ensuring that each release improves the system progressively and aligns with the project's goals. This methodology provides a clear path from concept to deployment, ensuring that each module adds value to the overall system while maintaining a high standard of quality and performance.

A. *Data Collection*

For our AR application, user data, session information, and dynamic content were stored in both MySQL and AWS S3. MySQL was used to store structured data such as user preferences, interaction history, and session statistics, allowing for efficient data retrieval and management. Custom 3D models, textures, and assets were stored in AWS S3, providing scalable and reliable cloud storage for large files. AWS S3's integration with the Content Delivery Network (CDN) ensured fast access to these assets globally, while MySQL handled the real-time management of user data and dynamic content.

B. *Data Preprocessing*

After the 3D models and textures were stored, several preprocessing steps were performed to optimize them for use in AR. This included reducing polygon counts for models using Blender's decimation tools to ensure smooth performance without compromising visual quality. Textures were resized and compressed to minimize file sizes, while maintaining fidelity. The models were then exported in AR-compatible formats like .obj and .fbx, which were later integrated into the AR system.

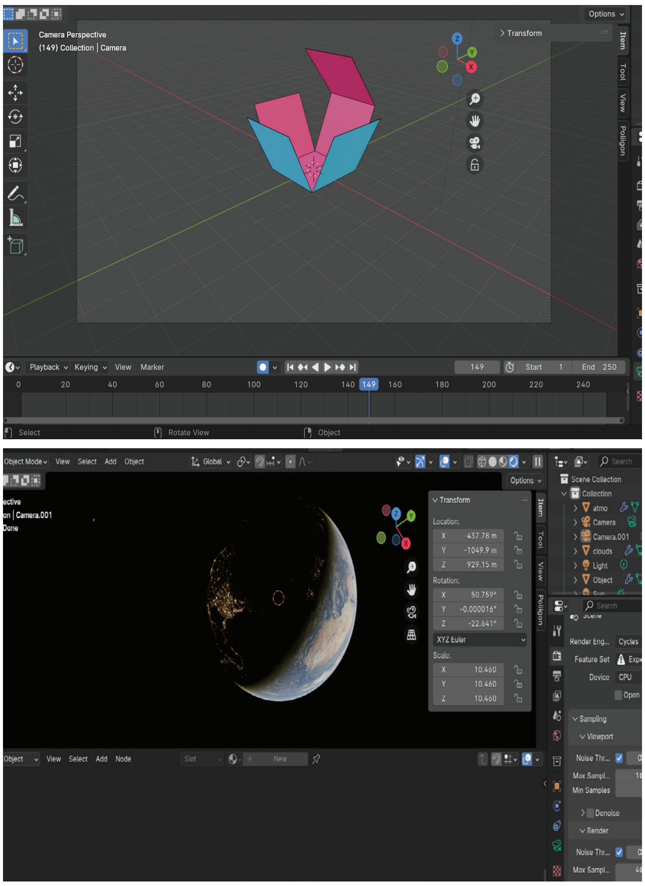

Fig. 2 3D models before data preprocessing

C. *Model Selection – AR-Compatible Architecture*

The models stored in AWS S3 were integrated into the AR environment developed with Unity. The system utilizes real-time tracking and object recognition, supported by AR SDKs like ARCore and ARKit. With Unity's AR Foundation, these assets were rendered and interacted with in a seamless manner, allowing users to engage with the AR content. The use of custom-designed models ensured that the visual and interactive elements met the unique needs of our AR application.

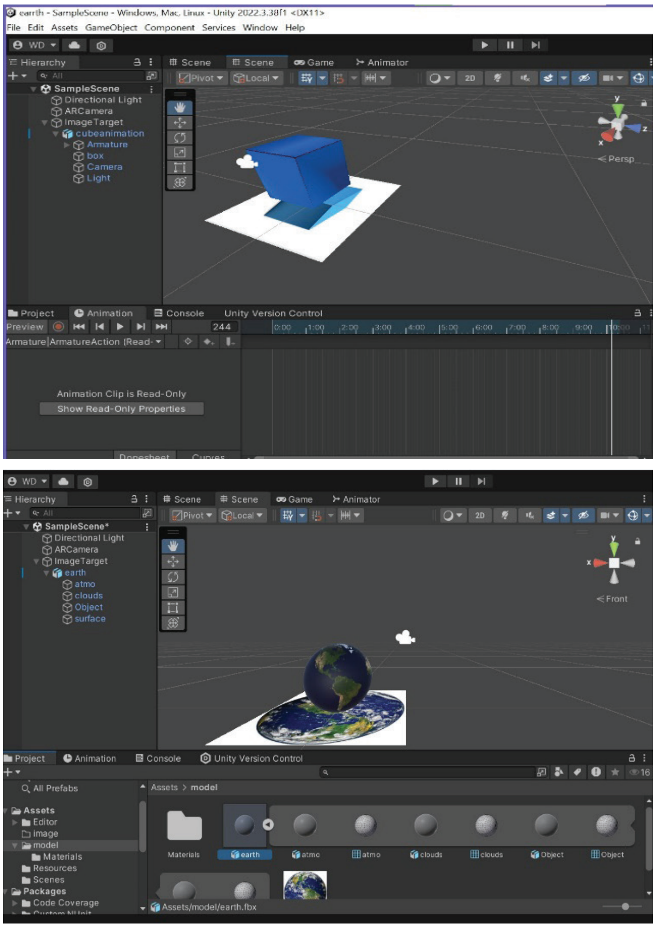

Fig. 3 Integrating the stored models into AR environment using Unity

D. *Backend Integration*

In addition to storing assets in AWS S3, Firebase Remote Config was used to manage and dynamically adjust the app's settings and features, providing real-time customization based on user preferences. For data management, MySQL was integrated to store user information, session data, and dynamic content that could be modified remotely, offering a personalized AR experience. This backend integration, combined with efficient storage solutions in AWS, ensured that the app could scale and deliver high-quality AR content while minimizing latency and maximizing performance across devices.

E. *System Architecture*

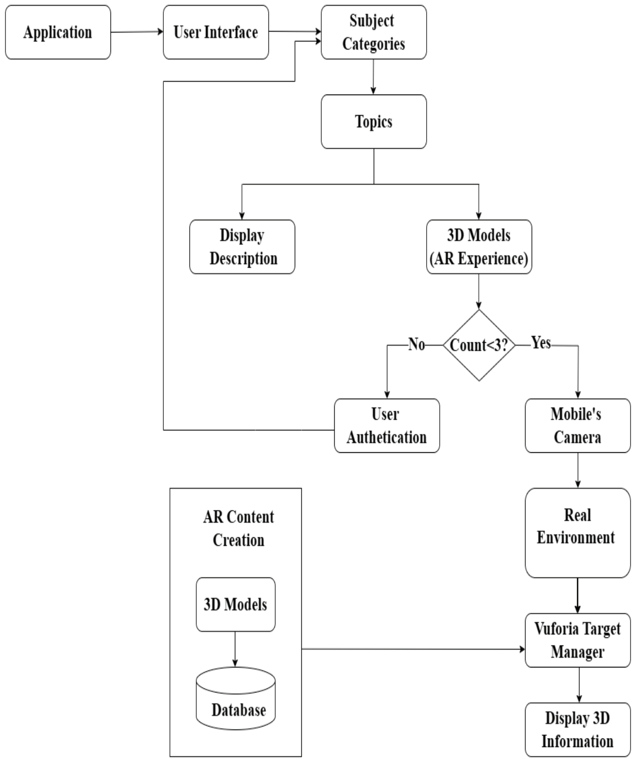

Fig. 4 System Block Diagram

1) *Architecture Overview:*

Neuron-X employs a three-tier architecture:

- Client-side (User Interface): The user interface (UI) is designed to be intuitive and user-friendly. Students interact with the application through a simple interface that allows them to select subjects, topics, and 3D AR content. The interface also provides navigation controls to guide the user through the learning experience.
- Application Logic Layer: This layer handles the logic behind the AR experiences, content rendering, and interaction with the 3D models. Developed primarily in Unity, this layer processes real-time data from the camera and sensors to overlay virtual objects onto the real world. It also manages interactions like rotating models, zooming in, or triggering animations within the AR scene.
- Database and Cloud Layer: The database stores user profiles, progress, and the AR models used in the application. This layer is powered by Firebase and AWS S3, providing secure, scalable storage and efficient management of 3D content. The cloud layer ensures

that the application remains accessible across different devices and offers real-time content updates.

F. *Flowchart*

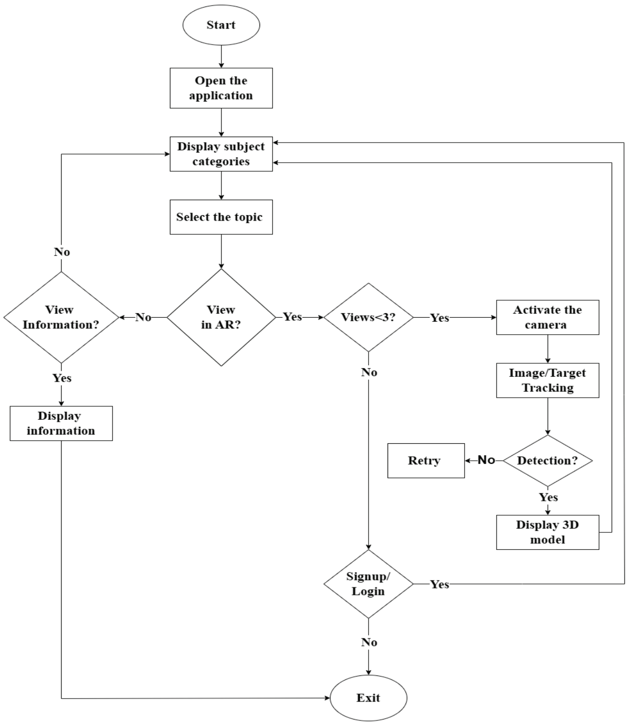

Fig. 5 Flowchart

G. *Sequence Diagram*

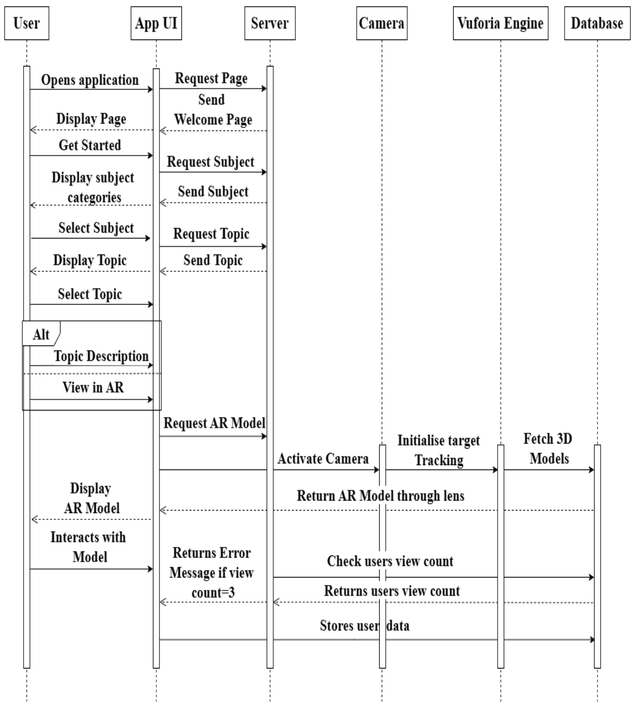

Fig. 6 Sequence Diagram

H. *ER Diagram*

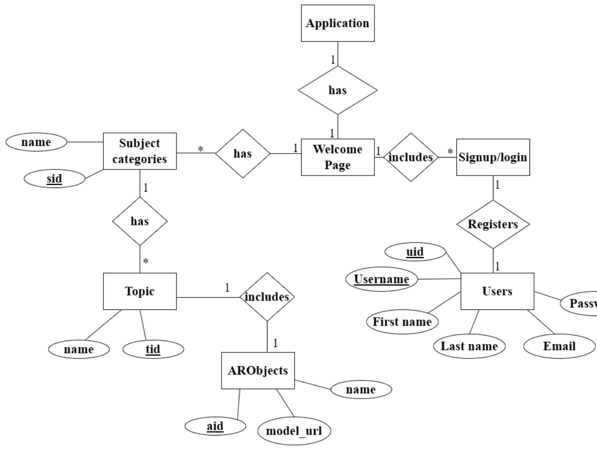

Fig. 7 ER Diagram

I. *Verification and Validation*

The verification and validation activities for our AR learning app focused on ensuring the proper functionality and security of user authentication (signup, login, password recovery) and AR/3D model rendering features. Verification activities included inspections, reviews, walkthroughs, and desk-checking. These processes ensured that the database, authentication logic, and AR features aligned with system requirements and performed reliably in various scenarios. Regular peer feedback and real-world scenario simulations helped refine the app's usability and identify any inconsistencies.

Validation activities involved black box and white box testing. Black box testing was conducted by classmates to evaluate key features from a user perspective, while white box testing involved a thorough review of the app's internal code for security and performance. Integration testing verified seamless functionality between authentication, database, and AR features. The AR features were validated by testing the accuracy and responsiveness of 3D model rendering under different conditions. These activities ensured the app met its educational, functional, and user experience goals, providing secure authentication and an engaging AR experience.

IV. Conclusions

Neuron-X has the potential to revolutionize the educational experience, particularly for students with diverse learning needs. By utilizing Augmented Reality (AR), the platform makes complex concepts easier to visualize, interact with, and understand. Early feedback from students has shown that AR significantly improves engagement, comprehension, and retention, particularly for students who struggle with traditional learning methods.

The application's modular design and flexibility make it suitable for a wide range of subjects and adaptable to various learning environments, especially in regions with limited access to quality educational resources. Neuron-X's ability to provide an interactive, hands-on learning experience for all students, including those with learning differences, positions it as an essential tool for the future of education.

While there are still areas for improvement, such as cross-platform compatibility and multilingual support, the initial results demonstrate that Neuron-X can be a game-changer for education, particularly in developing countries like Nepal. With continued investment in technology, content, and user experience, Neuron-X can help create a more inclusive, engaging, and effective learning environment for students worldwide.

Fig. 8 Fully integrated and working system

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