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EsAR: An Augmented Reality Application for Learning Volcanoes

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. ABSTRACT

Augmented Reality has become an important tool for improving how students learn complex science lessons. In many schools, instructional materials are often limited, outdated or not suited for interactive teaching. This affects subjects such as Earth Science where learners need clear visual explanations to understand processes inside the Earth. Teachers often rely on drawings and verbal descriptions which may not show the full structure or behaviour of natural events. Studies have also shown that inadequate learning resources contribute to lower academic performance, which highlights the need for better teaching tools.

EsAR was developed as a response to these challenges. It is a Markerless AR application that presents 3D volcano models, types of volcanoes and simple eruption simulations. By using a mobile device, learners can view these models in real space and see how volcanoes form and erupt. This makes abstract ideas easier to understand. Modern AR systems such as EasyAR use surface detection and SLAM to track the environment, which allows digital models to blend naturally with the physical world.

The application was created using the Waterfall Model. Each step, from gathering requirements to deployment, was completed in sequence. Unity 3D and C# were used to build the models and interactions. Storyboard and interface designs ensured the app remained simple and accessible to users.

The system was evaluated using selected ISO 25010 quality characteristics. IT experts, science teachers and students rated functional suitability, usability, reliability, performance efficiency, compatibility and portability. The overall rating of 3.77, interpreted as Excellent, showed that the application worked as intended and was easy to use on different devices.

The results show that AR can help address gaps in science education. EsAR offers a practical way to improve visual understanding and make learning more engaging. With further development, AR can continue to support better science instruction in schools.

Keywords — Augmented Reality, Unity 3D, C#, ISO 25010, Markerless AR

. INTRODUCTION

Instructional materials refer to the content and resources used to deliver a course, such as lectures, readings, textbooks, and multimedia tools. These materials are crucial in helping students understand lessons, yet many educators continue to face daily challenges due to the lack of sufficient learning materials, especially in subjects requiring interactive instruction like Earth Science. As a core subject in Senior High School, Earth Science involves understanding the Earth's structure, composition, processes, and environmental issues. Given its complexity, traditional lecture-based lessons, drawings, and storytelling are often not enough for students to grasp scientific concepts effectively.

Since the implementation of Senior High School in 2016, the Department of Education has struggled to consistently supply adequate modules and learning resource. It was revealed that teachers across urban and rural settings often resort to creating their own materials using personal funds, outdated books, recycled supplies, and traditional tools. Studies such as Toyosi (2018) and Awolaju (2016) emphasize that inadequate instructional materials negatively affect students' academic performance, highlighting the importance of properly designed and validated resources in teaching and learning.

With the advancement of technology, there is a need for schools and educators to adopt modern tools that support interactive and engaging learning. One promising innovation is Augmented Reality (AR), a technology that blends digital information with real-world environments. AR allows users to visualize 3D objects, interact with virtual models, and explore complex concepts more naturally. According to researchers like Chen (2019) and Chalimov (2018), AR enhances understanding, engagement, and retention of knowledge by making learning more immersive and enjoyable.

Studies further show the effectiveness of AR in improving learning outcomes, such as the research by Almohamadi (2018), which found that AR-based methods outperform traditional paper-based instruction. Integrating AR into Earth Science provides learners with an interactive supplementary tool that improves comprehension and makes the learning experience more meaningful.

A. Augmented Reality

Augmented Reality (AR) is defined by Hayes (2020) as an enhanced representation of the physical environment through digitally generated images, sounds, and sensory inputs. Its growing use in mobile devices and business applications highlights its role in emphasizing features of the real world to support analysis, data gathering, and smart interaction. The development of AR began in 1968 when Ivan Sutherland created the first head-mounted display, known as "The Sword of Damocles," which allowed users to interact with virtual objects. This innovation inspired further research, including Myron Kruger's 1974 "Videoplace," an early artificial reality system that required no wearable device. In 1990, Boeing researcher Tom Caudell introduced the term "Augmented Reality" to describe a head-mounted display used for assisting aircraft technicians.

AR advanced significantly in 1992 with Louis Rosenberg's "Virtual Fixtures," a fully functional AR system developed for the U.S. Air Force to enhance human performance. Further progress followed with the creation of KARMA by Feiner, MacIntyre, and Seligmann, which used knowledge-based AR for repair and maintenance tasks. AR soon expanded beyond laboratories into entertainment and media. Notable examples include Julie Martin's AR theater production "Dancing in Cyberspace" (1994) and Sports vision's televised NFL "yellow first-down marker" in 1998.

The 2000s marked rapid development, beginning with Hirokazu Kato's AR Toolkit, which provided developers with tools for creating AR programs. Mobile and gaming applications soon emerged, such as the first mobile AR game "ARQuake" in 2002. AR also influenced print media through interactive magazines like Esquire in 2009. Industries adopted AR as well, with Volkswagen introducing MARTA for technical repair guidance.

Modern AR adoption expanded further with Google Glass, Microsoft HoloLens, and the global success of Pokémon Go. Companies like IKEA also utilized AR for virtual product visualization. Today, AR influences retail, navigation, remote assistance, automotive industries, and events, demonstrating its wide-reaching impact. Understanding this evolution is essential, as AR has become deeply embedded in everyday life and remains a transformative technology across sectors.

B. Augmented Reality in Education

Augmented Reality (AR) is transforming traditional learning by offering interactive and immersive educational experiences. It enhances when and where learning can take place and supports both modern and conventional teaching methods. In the classroom, AR increases student engagement and deepens appreciation for the lesson content. With 80–90% of today's youth owning mobile phones and actively using them for social media, gaming, and even academic tasks such as homework and advanced reading, AR becomes a practical tool for modern learners (Kovach, 2020). Its accessibility through mobile devices makes it an effective medium for integrating technology into education.

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When used in classrooms, AR can turn ordinary lessons into dynamic and enjoyable learning experiences. It enriches textbooks and printed materials by providing virtual models, animations, and interactive elements. This makes classes more engaging and supports better comprehension, especially in subjects that require visualization and hands-on understanding. In public schools, several subjects—particularly in the hard sciences such as Physics, Biology, and Chemistry—would greatly benefit from AR because these fields require more than theoretical explanation. However, challenges such as outdated libraries, limited computer laboratories, and a lack of science equipment hinder effective teaching. AR can help fill these gaps by providing virtual simulations and interactive demonstrations that replace or supplement unavailable physical resources.

Research consistently shows that AR improves learning outcomes. Koehler et al. (2017) found that AR-based activities significantly enhanced students' understanding of complex scientific concepts. Beyond academic performance, AR also helps develop essential 21st-century skills, including critical thinking, creativity, and problem-solving. According to Liarokapis et al. (2018), AR enables students to engage in immersive scenarios where they must analyze information, solve real-world problems, and make informed decisions. Overall, AR offers an innovative and accessible solution to strengthen instruction, particularly in resource-limited educational settings.

C. Markerless AR

Augmented Reality (AR) can now be widely experienced through mobile devices and is commonly categorized into two types: marker-based and Markerless AR. Both provide real-time 3D interactive environments but differ in how they detect and place virtual objects. Markerless AR, as defined by Schechter (2020), overlays virtual 3D content onto a scene without relying on predefined markers. Instead, it analyzes natural features of the environment, using sensors such as accelerometers, compasses, and thermal positioning systems to understand the user's surroundings. This allows the application to accurately position virtual objects in physical space. Szczepaniak (2022) notes that the collected sensor data is then processed and displayed through the device to enhance real-world objects with digital information.

A key technology supporting Markerless AR is Simultaneous Localization and Mapping (SLAM). SLAM enables a device to map its environment while also determining its position within that map in real time. According to Ross (2021) and Martin (2019), this technique helps AR applications recognize 3D objects and track spatial changes, allowing digital augmentations to interact seamlessly with the physical world.

In this study, AR is utilized for tasks such as detecting flat surfaces and rendering 3D objects. These capabilities enhance user interaction and create a more immersive and enjoyable mobile AR experience.

System Overview

Figure 1 shows the architecture of esAR. Users should use a mobile device to utilize the system. The system used Markerless surface tracking, a feature of EasyAR System Development Kit, which recognizes significant features in the camera image, tracks differences in the positions of those features across continuous frames.

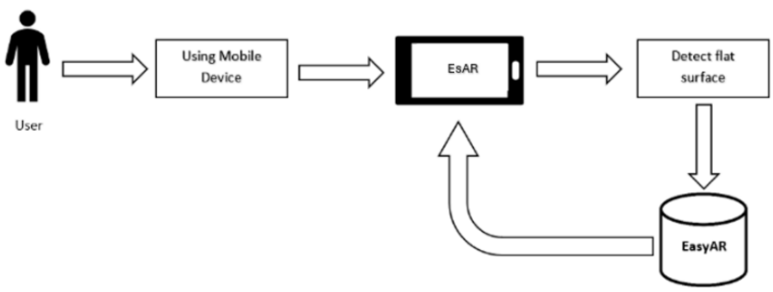

Fig. 1 Architecture of EsAR

Figure 2 shows the storyboard of EsAR. The system has different sections, namely: Start, Instructions, Settings, and Exit. Start section contains sub sections such as introduction to volcanoes, types of volcanoes, anatomy of

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volcano and simulation of volcanic formation and eruption. Instructions section shows the instruction on how to use esAR. Settings shows graphic and sound setting. Lastly, Exit will close the application once clicked.

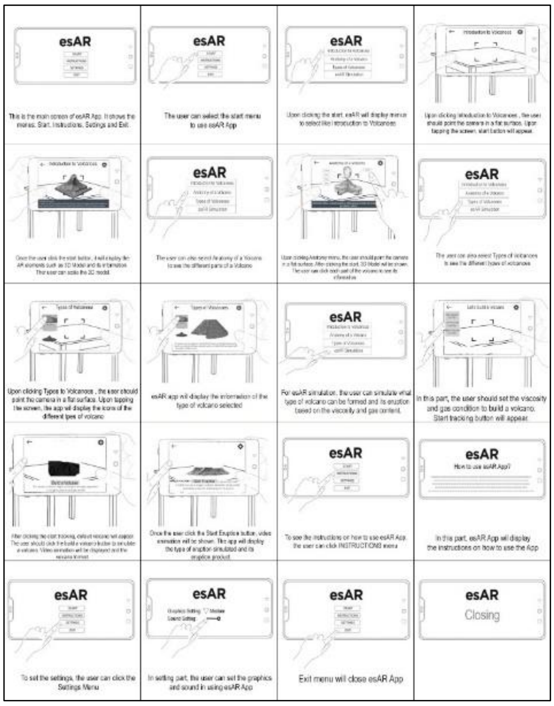

Fig. 2 Storyboard

METHODOLOGY

The study used Waterfall Model illustrated in Figure 3 to describe the activities performed in the development of the system. This model was utilized because it was simple and easy to understand and use. The software development life cycle model defines the phases of the software cycle as well as the sequence in which those phases were carried out. Each phase was generated deliverables that were needed by the following phase of the life cycle.

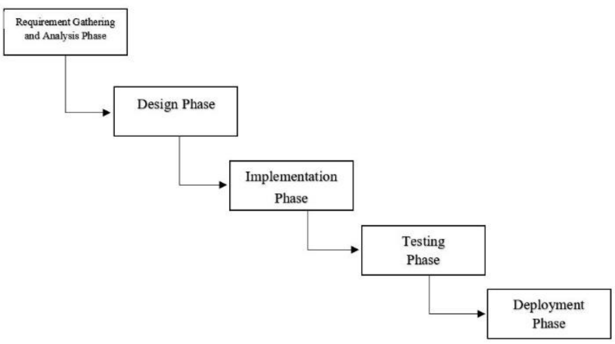

Fig. 3 Waterfall Model

The process followed several key phases. In the Requirement Gathering and Analysis Phase, the needed system requirements were collected through interviews. Continuous interaction between the proponents and users ensured a clear understanding of system expectations.

During the Design Phase, the creation of diagrams. These designs were reviewed and validated against the system requirements, and the necessary hardware and software specifications were finalized.

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The Implementation Phase involved coding the system modules. The proponents used Unity 3D to create 3D models and C# for programming. Icons and other interface elements were developed, and debugging was conducted to reduce system errors.

In the Testing Phase, the system was evaluated to ensure that it met the requirements gathered earlier. The testing checked functional suitability, usability, portability, and performance efficiency. Any gaps identified were addressed before finalizing the system.

Finally, in the Deployment Phase, the completed system was prepared and released to users as the final product.

High-Fidelity Wireframes

Fig. 4 shows the menu of the AR application. It shows 4 sections: Introduction to volcanoes, anatomy of volcanoes, types of volcanoes and esAR Simulation

Fig. 4 EsAR Menu

Figure 5 shows the AR application presenting a 3D model of a volcano. The app displays the volcano's shape and surface clearly, helping learners see how molten rock and gases come out through the vent. It gives a quick visual guide to what a volcano is and how it forms.

Fig. 5 Introduction to Volcano Section

Figure 6 shows the AR application displaying a cutaway model of a volcano. The app labels each major part such as the magma chamber, conduit, vent, crater, lava and parasitic cone. This helps learners see how the inside and outside parts connect and how magma moves through the volcano.

Fig. 6 Anatomy of a Volcano

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Figure 7 shows the AR application displaying different types of volcanoes. The app lets learners view cinder cone, composite and shield volcano models, making it easier to compare their shapes and features in 3D.

Fig. 7 Types of Volcanoes

Figure 8 shows the AR application simulating an eruption result. The model displays flowing lava on a shield volcano and explains that the eruption is gentle because the magma has low silica and low gas content. This helps learners see how different magma properties affect eruption style.

Fig. 8 Types of Volcanoes

RESULTS AND DISCUSSION

Twelve evaluators participated in the ISO 25010 assessment: three IT experts, two science teachers, and seven students. Each group rated the system across the selected ISO 25010 quality characteristics using a 4-point Likert scale.

Functional suitability

IT experts rated the system highly (3.90) and confirmed that all features worked as expected. Teachers (3.80) said the AR sections accurately represented the lesson content. Students (3.70) found the functions easy to use. The overall mean of 3.77 indicates Excellent functional performance.

Usability

Teachers gave the highest usability score (3.90), noting that the interface was simple and clear for classroom use. Students (3.75) said they understood the controls quickly. IT experts (3.85) noted minimal risk of user errors. Usability earned an Excellent rating.

Performance efficiency

All groups reported smooth AR tracking and fast model loading. IT experts rated this at 3.80, teachers at 3.70 and students at 3.60. The overall mean of 3.67 falls under Excellent.

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Reliability

The system showed stable performance. IT experts (3.90) confirmed no crashes during repeated tests. Teachers and students also experienced stable results. The overall mean of 3.72 indicates Excellent reliability.

Compatibility

The application worked on devices with different screen sizes and Android versions. Ratings ranged from 3.70 to 3.85. The overall mean of 3.75 is Excellent.

Portability

This category received the highest overall rating. IT experts gave 3.95 after testing the app on multiple Android versions. Teachers and students also found installation easy. The overall mean of 3.88 is Excellent.

Overall Interpretation

The combined ratings from three IT experts, two science teachers and seven students gave the system an overall mean of 3.77, interpreted as Excellent. This shows that the AR learning tool meets the selected ISO 25010 quality criteria and was effective as a supplementary tool for learning Volcanoes.

CONCLUSION

The development of esAR provided a practical way to support the teaching and learning of volcanoes. The system used Markerless Augmented Reality to present 3D models and simple simulations that helped learners understand structures, types and eruption behaviour. The Waterfall Model guided the work from requirements up to deployment and ensured that each phase met its purpose.

Results from the ISO 25010 evaluation showed strong performance across all selected quality characteristics. IT experts, science teachers and students all rated the tool as Excellent. They confirmed that the features worked as intended, the interface was easy to use, and the AR models loaded smoothly. They also noted stable performance on different devices, which supported the high portability score.

The findings show that AR can help address gaps in instructional materials, especially in subjects that require visual and interactive learning. EsAR offered a clear view of complex concepts and supported better understanding without relying on expensive laboratory equipment. The tool can serve as a supplementary resource and can be improved further with added simulations and extended content.

Overall, the study showed that AR was a useful and accessible technology for enhancing science learning in schools.

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