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Augmented Reality for Early Science Education: Development and Evaluation of a Mobile Learning Application

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Abstract−Learning science at the kindergarten level often faces challenges due to children's limited attention span, difficulty visualizing abstract concepts, and the lack of engaging learning materials. Augmented Reality (AR) offers an effective solution by transforming static content into interactive, visually rich experiences that can enhance understanding and motivation. This study aims to develop and evaluate an AR-based mobile application designed to support early science learning among kindergarten children. The application leverages common smartphone camera capabilities to provide accessible and immersive learning activities. A user study involving 30 children aged 4–6 years was conducted to assess usability, engagement, and learning support. Observations, simple task performance, and teacher feedback were used as evaluation methods. Overall, the findings indicate that AR features increased students' curiosity, improved their interaction with scientific content, and supported more effective learning experiences. The study highlights AR's potential as a valuable tool for early science education. When AR is thoughtfully integrated, it can enrich early science learning without increasing instructional complexity. To enhance practical relevance, AR in early science education should be curriculum-aligned, developmentally appropriate, and combined with hands-on inquiry.

Keywords: Augmented Reality; Early Science Learning; Kindergarten Education; Mobile Learning Application; Interactive Learning

1. INTRODUCTION

Science education in early childhood plays a fundamental role in shaping children's curiosity, problem-solving abilities, and foundational understanding of the natural world. However, teaching science to kindergarten-aged children remains challenging due to their limited cognitive development, poor concentration, and difficulty in grasping abstract scientific concepts (Maraisane et al., 2024). Traditional teaching methods that rely heavily on verbal explanation or static images often fail to capture young learners' interest, resulting in low engagement and minimal conceptual understanding (Hu, 2024). Therefore, there is a growing need for innovative approaches that make science learning more interactive, concrete, and enjoyable for young children.

Recently, technological advancements have introduced new opportunities to strengthen early science education. Augmented Reality (AR) has emerged as a powerful tool capable of bridging abstract concepts with real-world visualization (Thangavel et al., (2025). AR overlays digital objects, animations, and information onto the physical environment, enabling children to explore science content through multisensory experiences. Research has shown that AR can enhance attention, motivation, and comprehension by transforming passive learning into active discovery (Hammuzamer et al., 2024). Furthermore, mobile AR applications are highly accessible, as most smartphones today are equipped with built-in cameras and sensors that support AR functionality. This makes AR a practical and scalable solution for early childhood classrooms.

Recognizing these advantages, this study focuses on developing and evaluating an AR-based mobile application designed specifically for science learning among kindergarten children. The application integrates interactive features, simple animations, and age-appropriate content to support concept exploration in a playful and engaging manner.

2. RESEARCH METHOD

2.1 Literature Review

In the world of technological development, mobile applications have become the focus of public attention these days. The rapid development of mobile applications can affect its use in various fields including education. Learning aids are changing in line with the development of increasingly advanced technology. Modern technologywill provide an effective and efficient learning experience. (Fatih, 2021). Modern technologies such as AR used in learning can have a good impact on the level of user motivation, deep attention span, knowledge, literacy, high creativity, and level of satisfaction. (Cascales et al., 2013). With the developmentof technology, AR has a variety of applications used in education as interactive teaching aids. (Yuen et al., 2011).

2.2 Science Education In Early Childhood

Early childhood science education is essential for developing foundational inquiry skills, curiosity, and early scientific reasoning. However, young learners often struggle to understand abstract scientific concepts due to their cognitive development stage, limited attention span, and need for concrete, hands-on experiences (Piaget, 1973; Gelman & Brenneman, 2012). Traditional instructional methods that rely on verbal explanation or two-dimensional visuals often fail to stimulate deep engagement or conceptual understanding. As a result, researchers highlight the importance of multisensory, play-based, and visually enriched instruction to support children's early science learning (Eshach, 2006; Fleer, 2009).

2.3 Augmented Reality in Education

AR is a technology that allows objects consisting of visual or real objects to be shown through a digital environment. AR can also be classified as an environment that allows people to interact directly with virtual objects created to be placed in a real environment to provide convenience to the public (Nur Fadziana et al., 2025). Through the use of AR, users can feel the real world of reality through the digital environments and virtual objects and this does not change the real environment in the real world. (Mohd Razif Mustapha et al., 2023; Nielsen et al., 2016),

AR blends digital content with the physical environment, enabling learners to interact with 3D models, animations, and contextual information in real time (Azuma, 2001). Studies consistently report that AR enhances motivation, attention, and conceptual visualization due to its immersive and interactive affordances (Radu, 2014; Cheng & Tsai, 2013). Mobile devices equipped with cameras and sensors make AR highly accessible for educational settings, including early childhood classrooms. AR's ability to simplify complex concepts through dynamic visualization makes it particularly suitable for teaching scientific phenomena that are otherwise invisible or abstract (Ibáñez & Delgado-Kloos, 2018).

Augmented reality is one of the exciting technologies to use in education, and as a tool to motivate kindergarten students involves several senses through a combination of sound, sight, and touch. The ability to use AR in learning enables a multisensory system specially designed for children aged 3-5 years. The multisensory system will be used by students in a learning environment shaped by the presence of images, objects, and tangible objects. Therefore, the AR platform assists learning with the sensory experience felt by the student. AR helps a lot in the learning and teaching process that involves the students' senses through interactive activities. (Lim & Kim, 2010). The use of various elements such as 3D model design, graphics, animation, and quality audio display in the learning process using technology is very important. In addition, the use of 3D model design can attract user attention because it can be seen from various angles, Therefore, the use of 3D design elements along with graphics, animations, and audio displays can enhance students' understanding of the learning process. (Valarmathie, 2015).

2.4 Related Study

Previous studies demonstrate the positive impact of AR learning science. A comparative analysis method has been carried out to identify appropriate component and elements of existing related AR science application. Reviews show that AR is effective in enhancing motivation, engagement, and immediate learning outcomes when activities are scaffolded and aligned with learning objectives (Garzón & Acevedo, 2019; Bacca et al., 2014). However, these reviews also note variability in learning gains, emphasizing that AR is most effective when thoughtfully integrated into instruction rather than used solely for novelty. Effective design principles include age-appropriate interaction, guided exploration, and clear instructional scaffolding. To provides a more comprehensive comparative analysis this study also carried out the matrix analysis table as tabulated in Table 1.

Table 1. Matrix analysis AR mobile application in Science learning.

Study (Year)	Science Topic	Key AR Features	Padagogigal Approach	Evaluation Method	Key Outcomes	Learner Level
Bacca-Acosta et al. (2024)	Chemistry (atoms & molecules)	Visualization, interaction, contextual learning	Constructivist & inquiry-based	Systematic literature review	AR effectiveness depends on usability, instructional design, and learner age	High school
Simsek (2024)	Environmental Science	Simple 3D models, audio narration	Play-based learning	Quasi-experiment al	Improved understanding and attention	Early childhood
Faria (2024)	Earth Science (Volcanism)	3D terrain models, animations	Inquiry & visualization	Mix methods	Better spatial and conceptual learning	Primary Secondary
Mansour et al. (2025)	General Science	Embodied interaction, gestures	Embodied learning	Experiment al study	Strong engagement and conceptual gains	Primary
Ibáñez & Delgado (2020)	Physics (Circuits, mechanics)	Simulations, 3D models, contextual overlays	Inquiry-based & problem-based	Systematic review	AR supports conceptual understanding and motivation when	Secondary

Study (Year)	Science Topic	Key AR Features	Padagogigal Approach	Evaluation Method	Key Outcomes	Learner Level
	STEM / Science (Review)				aligned with pedagogy	
Radu et al. (2020)	Ecology, biodiversity	3D visualization, interaction, spatial overlays	Constructivist & experiential	Meta-review	AR improves engagement and understanding but may increase cognitive load if poorly designed	K-Higher Ed

This study adopts the ADDIE model to develop the AR Science Mobile Application. It consists of five main phases which are (i) analysis, (ii) design, (iii) development, (iv) implementation, and (v) evaluation. The details of each phase were described in Table 2.

Table 2. ADDIE model of AR Science Mobile application.

Phase	Description
Analysis	Identify the target user Analysed the user needs - content Determine the applicable feature of the application
Design	Design the storyboard Design the interface Organize the structure and content
Development	Develop the application 3DS MAX software has been chosen for designing the 3D model and texturing for each model. Adobe Premiere CC software would use for platform editing Unity 3D software has been chosen to make Augmented Reality
Implementation	AR SAINS application installed on a smartphone that uses the Android platform.
Evaluation	Involve the experts and target users to evaluate the AR SAINS mobile application.

2.5 Design and Development of AR Science mobile applications

The AR SAINS mobile applications is an applicaton which focuses on early Science for pre-school children age four to six years old. The purpose of this application is to help children to interact with virtual objects and relate them to their real physical world. It can be an additional instructional tool to motivate children to learn abstract concept in a fun and enjoyable way.

AR SINS consist of three main menu; "*Pembacaan*", "*Imej* AR", and "*Teka-teki*" as depicted in Figure 1. Under the menu "*Pembacaan*", children will learn about solar system, animal habitats and plant evolution. Children can read the information about the features of the planet, animals, and plants. The function of '*teka-teki*' is to test children's knowledge after they explore the application. Figure 1 illustrate some of the main interfaces of AR SAINS mobile application.

Figure 1. Interface of AR SAINS mobile application.

In the design phase, the interface for this application was sketch using Adobe Illustrator CC (Figure 2). Then, based on previous design, the process followed by including the description and user activity on the bottom for each interface storyboard. This is important to guide the flow of this application. Figure 3 shows the example of making a description and user action for the interface design.

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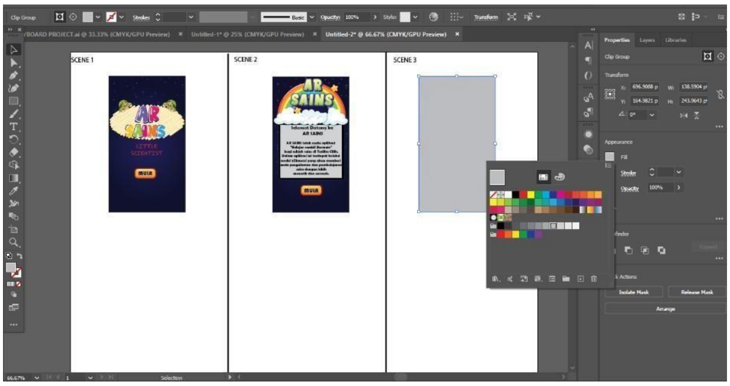

Figure 2. Example of interface design for AR SAINS mobile application.

Figure 3. Example of making description and user action.

3DS MAX software has been chosen for designing the 3D model and texturing for each model. Then, FBX files from 3DS MAX have been imported into Unity 3D software. Figure 4 shows the example of fish 3D modeling in 3DS Max.

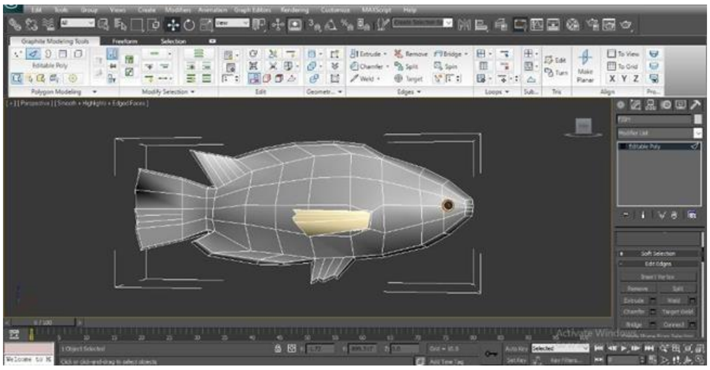

Figure 4. Example of fish 3D modeling in 3DS Max.

Next, for development of the AR SAINS mobile application, the Unity 3D for android software has been chosen. This software is used in the app to produce AR. Therefore, this software requires for interface, buttons, and coding for each scene**.** Figure 5. shows the example of interface design develop in Unity.

Figure 5. Example of interface design development in Unity.

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Lastly, Adobe Premiere CC software would have been used for editing. In this software, the whole audio would be imported from the downloaded and cut off whether it was suitable or not for the intonation and voice in this project. After finishing the process of development of AR SAINS mobile application, this application then has been installed on a smartphone that uses the Android platform.

2.6 Evaluation

The evaluation phase involved the evaluation of AR SAINS mobile application by experts and users. Experts are involved in examining content and design while user evaluation is to observe children's engagement with the application. For experts' evaluation, a science teacher, a kindergarten manager, and three experts for design were involved.

During the evaluation process, all experts were given explanation regarding the objective of the evaluation. Then, the experts were allowed to walk through the AR SAINS mobile application in their ample of time. While exploring the application, the experts were free to contribute comments and suggestions for improvement. Figure 6 shows summaries of comments from design experts.

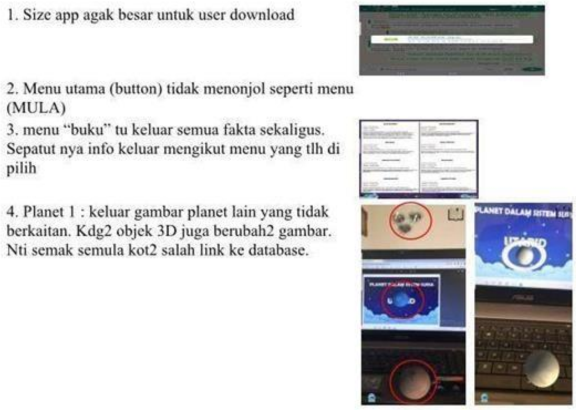

Figure 6. The summarize comments from a design expert.

In addition, to get feedback from potential users, this study gets permission from Tadika Cilik to conduct an evaluation. After permission has been given, appointment has been set. Focus group evaluation was conducted with 30 respondents from Tadika Cilik. Respondents were given ample time to explore the application. While users were using the application, the researcher observed on how respondents interact with the application and take note time they spent on every feature.

4. RESULTS AND DISCUSSION

Content experts involved a manager at Tadika Cilik and a science teacher. They explored the content, syllabus, and function of this application. Some of the comments for this application need to be an improvement for future work.

a. The teacher suggest to including audio translation for each interface in this application. For the focus group 4 years old, they cannot understand the function and text in this application.
b. The text in this application is a bit confusing for the focus group to understand. In kindergarten, their teacher teaches them standard alphabet text, and if the text used is different, they are confused and hard to understand.
c. They also suggest minimal text for important information only. For example, the features of the firstplanet are hard to read because of the type of text and information. The figure above shows the improvement for this application. Figure 11 shows the text in a paragraph and is hard for a focus group to understand. Then the second figure shows the improvement to minimal and important text only included for each interface.

Figure 7. The improvement for AR SAINS.

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Based on Table 3, the total are 30 participants from pre-school children at TadikaCilik involved in the evaluation phase in this study. The participants have selected from 4 to 6 years old. 17 participants are male (57%), and 13 participants are female (43%).

Table 3. Demographic and Age of focus group.

	Demographic	Frequency	Percent
Gender	Male	17	57%
	Female	13	43%
	4 Years Old	3	10%
Age	5 Years Old	12	40%
	6 Years Old	15	50%

The findings from the observation reveal that respondents show their excitement while interacting with the application. They can use and control the AR SAINS mobile application well and can interact easily even though they are first time using AR technology. They tried each function in the application, and they found that AR function attracts them more (Figure 7). They also enjoyed the games features, and they thought that these features helped them to learn easier about the planets, animals, and plants. They also ask questions about the planet's environment and why humans cannot live there. In addition, when the questions from the games appear, they do not respond quickly but they take time to think about the question before answering the question. For learning features, children start to quire and ask their teacher for more explanation about the topic.

Figure 8. Respondents explored AR SAINS in focus group.

The findings can be interpreted through established learning theories. From a Piaget perspective, kindergarten children are in the preoperational stage, where learning is most effective through concrete, visual, and sensory experiences rather than abstract textual information (Piaget, 1973). The observed difficulty in understanding long and unfamiliar text indicates a mismatch between the application design and children's cognitive development. From Vygotsky's sociocultural perspective, the recommendation to include audio translation highlights the importance of language and scaffolding in supporting learning within the Zone of Proximal Development (Wertsch, 1985). Audio narration and minimal, familiar text act as mediating tools that support comprehension and reduce cognitive load. These findings suggest that AR applications for early science education should prioritize visual and auditory cues over text-heavy interfaces to align with children's developmental and sociocultural learning needs.

4. CONCLUSION

In conclusion, the use of AR in learning would motivate and attract preschool children more interested in learning science. AR is particularly effective in making abstract or invisible scientific concepts concrete, which is crucial for young learners. In early childhood and kindergarten contexts, simple AR interactions, visual clarity, and guided activities yield positive learning outcomes. Despite the positive outcomes observed, this study has several limitations that should be acknowledged. The sample size was relatively small and limited to a single kindergarten context, which may affect the generalizability of the findings. The evaluation focused primarily on short-term engagement, usability, and immediate learning support, without examining long-term knowledge retention or transfer of learning. In addition, the study relied on observational data and teacher feedback, which may introduce subjectivity. Technical constraints, such as device availability and varying levels of teacher familiarity with AR technology, may also influence implementation effectiveness. Future development should address these limitations by involving larger and more diverse samples across multiple educational settings. Longitudinal studies are recommended to examine sustained learning effects and retention over time. Enhancing AR applications with adaptive content, integrated formative assessments, and teacher monitoring features may further improve learning outcomes. Aligning AR content with national early childhood curricula and providing structured teacher training will support wider adoption and sustainability.

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