User Evaluation on a Mobile Augmented Reality Game-based Application as a Learning Tool for Biology

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Abstract **– It is challenging to comprehend abstract information on a scientific topic. In essence, AR could display abstract scientific information excitingly and graphically, improving the students' learning interests and performance. Their critical engagement could be enhanced further through AR's visualisation capability, achieved via active learning in an AR-game environment. Hence, this paper proposed and described a reflection on a mobile AR game, ARCell, involving cell biology. This game is designed to help students learn about the structures of animals and plant cells via an AR tapping game and a quiz module. This study recruited thirty-two participants. The usability results showed that the game was practical and highly developed, predicated on the different usability factors. They were keen on more educational content on biology, which included challenging game features in the AR game module.**

Keywords **– Augmented Reality, game-based learning, usability and mobile application.**

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1. Introduction

Augmented Reality (AR) combines real-world environments with computer-generated objects, allowing users to naturally interact with overlaying 3 dimensional (3D) objects in the physical environment [1]. It has become increasingly accessible, affordable, and popular as advanced equipment is no longer required, which can be conveniently used on smartphones. Notably, the AR adoption in education has simultaneously increased, exhibiting potential in teaching and learning. The process creates an interactive visual learning form to provide a better learning experience. Thus, this idea allows educators to leverage the concept of interactive experience in an educational setting.

Previous studies have drawn a common conclusion that AR increases the learners' motivational engagement and enhance their learning process [2], [3], [4]. Fundamentally, the idea supports learning by providing visual and interactive experiences that allow an in-depth understanding of conceptual knowledge. It provides seamless interactivity between real and virtual worlds to users, lacking from other forms of technology. For instance, they can interact with the virtual object overlay on a physical book [5], making the teaching material more engaging and easier to understand. Ultimately, it expands self-learning opportunities to help users develop their understanding of the AR content topic.

One of the advantages of AR technology is visualize the object that is invisible to the naked eye. For instance, among the biology subjects, secondary school students must understand an organism's fundamental functions, including a living cell. However, it cannot be seen with the human eye due to its minuscule nature, and thus a microscope is required to see them. Furthermore, the textbooks' 2 dimensional images make it challenging for them to understand cell structure and its organisation, specifically for complex cell structures.

Hence, it is critical to resolving their issues in understanding the theories and concepts of science topics that require significant imagination.

Present-day students are generally disinterested in scientific theories, primarily via textual descriptions in various subjects. AR can provide them with significant engagement through 3D visualisation, especially in cells, which can convert information effectively compared to written texts and 2D images. Furthermore, AR can be embedded with the game's principal, making them substantially dynamic and interactive. In essence, it will create a game-based learning environment where students experience the relevant game using AR technology in a learning context. This approach ultimately makes it more appealing for the students to learn about the related topic.

The research on AR game applications in education is still in its infancy, where various research questions are unexplored. In this study, we developed a mobile AR game on the biology subject, specifically related to cells. The mobile AR game is akin to the Fruit Ninja's game elements with an additional quiz module embedded into the application, introducing a new way for users to learn about cells. This study subsequently evaluated the developed mobile AR game from the usability perspective to investigate its potential. Finally, the data and opinions from the evaluation phase serve as a base for future improvement.

2. Background

AR is an emerging state-of-the-art digital technology supported by its ability to provide information through a highly interactive user interface based on a real-world environment. Furthermore, the constant rise of smartphone usage provided easy access for them to utilise this technology. Consequently, AR technology utilisation in education has become a crucial research topic [6]. This technology can significantly advance in educational settings as it creates discovery-based learning experiences for students through immersive environments [7]. Previous studies have discussed the positive aspects of AR's integration in education, including improvements in academic performance, learning achievement, and spatial skills. Others include enhancing learning motivation, ensuring permanent learning, positive attitude and decreasing cognitive load [6, 8-10].

Research on AR has been conducted for different ages; for instance, [11] developed educational magic toys using AR at the preschool level. The application comprising flashcards and matching cards is designed for preschoolers between five and six.

They were taught colours, fruits, vegetables, numbers, shapes, and vehicles based on these cards. The study revealed that AR is beneficial for early childhood education in enhancing cognitive skills. Similarly, [7] analysed children's spatial skills through AR Sandbox application. During the study, the children between four and five were facilitated with available tools and guided through social interaction. The application allowed the children to express their imagination and, at the same time, enhance their spatial understanding. Meanwhile, [12] presented a detailed feasibility analysis of AR technology in preschool education. It was found that the method can significantly stimulate the children's learning enthusiasm. Researchers discussed students' difficulties understanding sophisticated abstract concepts at the primary and secondary school levels. Thus, they emphasised the importance of integrating enhanced visual aid to help them comprehend such vast concepts. In another research, a science subject learning outcome is analysed by integrating AR technology into the "solar system and beyond" module [13]. The experiment involves two middle school students categorised into experimental and control groups. The result showed a positive response against the experimental group as students were interested in learning via an advanced and interactive manner.

Similarly, another study employed AR-based applications in teaching biology [14], which found significant attitude differences in the students towards the course, inducing positive learning outcomes. Meanwhile, a comparative analysis was conducted on the students' learning achievement, cognitive abilities, and behavioural patterns, which are compared with the computer and non-computer-based AR application learners [15]. The results concluded that students who learned via the AR application showed excellent performance. On a similar note, AR was applied in a higher education setting to support innovative teaching and learning experiences such as engineering [16]. The study developed a simulator for detecting electrical machines and their behaviour to connect the theoretical explanations in classrooms and laboratory practices. This approach is achieved by utilising AR and bridging theory with practical learning. The study by [17] showed an AR approach to train electrical engineering students on electrical components, circuit designs, and electrical devices such as multimeter. The AR system enabled them in learning to measure current, voltage, and resistance using a this device. Another study used the technology to provide a graphical representation of the human body, which supports learning of human anatomy [18].

In a more complex case, AR improved radiological image visualisation using augmented reality to diagnose and monitor the surgery [19]. Given the points above, AR technology utilisation is evidently versatile, which can be innovated into concepts such as Game-based Learning (GBL).

GBL refers to the concept of combining the game principal and instructional design approaches in a learning environment. Moreover, it can complement or supplement existing learning methods to create an engaging learning atmosphere for students [20, 21]. GBL and AR collectively yield a new term called augmented reality game-based learning (ARGBL). A study demonstrated an outdoor-based AR learning game aiming to increase the experience quality [22]. The game focused on a zoo environment where users are required to locate the point of interest in the zoo and answer quizzes. Overall, the game increases the possibility for users to learn in natural surroundings, thus increasing the aspects of learning. Extending the points above, [23] used location-based AR game concepts in mathematics. Students utilize the smartphones' GPS to find the point of interest, triggering the mathematical question. A series of numbers are then presented in a balloon, which the students must tap to reveal the correct answer. Accordingly, the results displayed that the students were enthusiastic about learning the subject using this game. Meanwhile, a study proposed the ARGBL with a slingshot shooting-game concept for the English learning system [24]. The system pronounces the English alphabets and words presented inside a bubble, and students must shoot it to reveal the correct answer. The study concluded that the ARGBL approach is more effective in improving learning motivation than common game-based English learning [24].

Correspondingly, ARGBL was applied in a chemistry experiment learning [25], in which the players must scan the AR card to collect the necessary apparatus or solution required for the experiment. Next, the application shows a virtual environment, and students can run the experiment based on the collected material. The evaluation results indicated that the AR integration and interactive laboratory enhance students' learning experience with a high degree of participation. To date, there is a wide range of studies on AR solely in the education context, though the potential of ARGBL for learning remains unclear. Hence, this predicament requires more studies to understand and explore its potential [26]. This study investigated the possibilities of ARGBL akin to the Ninja Fruit game-like concept to teach about the cell topic.

3. Mobile AR Game-Based Application

In this paper, a mobile AR game-based application named ARCell was developed to explore cell biology, where Figure 1 illustrates the game process. The first step in the pipeline includes activating the camera to capture the input video, which is then analysed using the Vuforia SDK. This phase involves pre-processing, detection, and recognition of the images. The application went to the different modules to display the corresponding 3D objects based on the recognised AR marker. Subsequently, the Vuforia tracking algorithm calculated the displayed 3D objects on the correct location. Users can interact with the application using different interactions, such as touch interaction in the learning and game mode. Finally, users were required to select the AR VuMark marker [27] and place it into the answer slot on a physical quiz board.

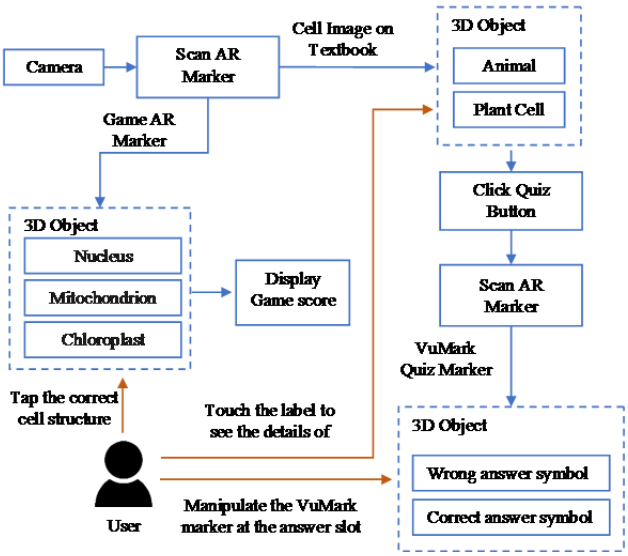


Figure 1 ARCell pipeline

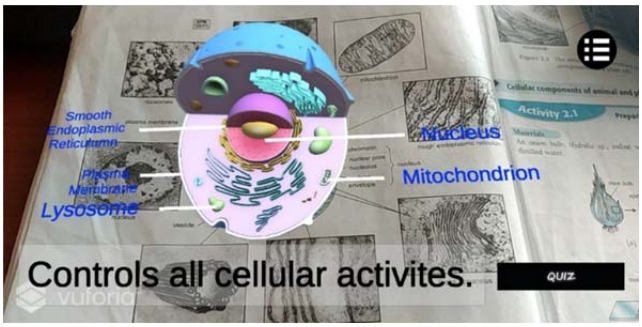
3.1. The ARCell Module

The application's three key modules comprise learning, quiz, and AR game modules. The first one considers the learning module allowing users to scan the textbox, enabling them to visualise the virtual 3D cell model (Figure 2). The cell structure was labelled with virtual text where users can select to show detailed information displayed on the bottom screen, providing them with a better understanding. Next, the users can take a quiz module to test their knowledge about the cell structure, and at the same time, AR is utilised. Moreover, a specially designed physical board represents the cell structure.

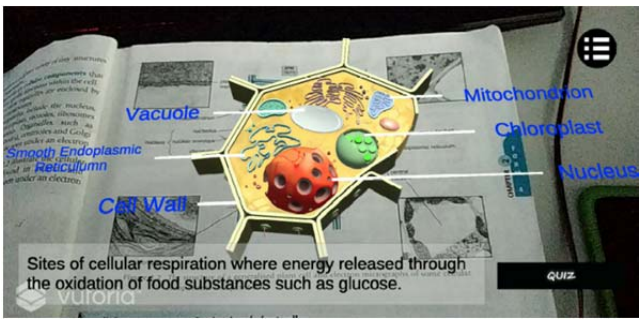
The board exhibited four blank spaces that enabled users to put the corresponding AR VuMark marker into the spaces to answer the quiz. Finally, the game detects the correct answers based on the AR marker (Figure 3).

The final component is the game module, at which users must scan the game marker to initiate the game. It is similar to the game Fruit Ninja, where users must tap a 3D model to obtain the score. In this case, the 3D model is the cell structure, comprising

the nucleus, chloroplast, and mitochondrion. These cell structures were then randomly generated and circulated on the AR screen. However, the game life will be deducted if the users tap the wrong cell structure and vice versa, as instructed by the game agent model (Figure 4).



(a)



(b)

Figure 2 Visualisation of 3D (a) Animal Cell and (b) Plant Cell on the Textbox in the Learning Module

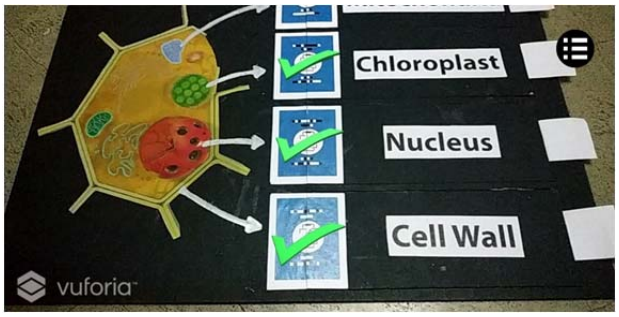


Figure 3 The Quiz Module with Vuforia Vumark AR Maker

(a)

(b)

(c)

Figure 4 Visualisation of 3D (a) Nucleus and (b) Mitochondrion and (c) Chloroplast In-game Module

4. Evaluation Results and Discussion

Thirty-two participants have been recruited to conduct the usability testing on ARCell, encompassing 17 females and 15 males. Accordingly, the convenience sampling technique was used to recruit the participants to understand the developed ARCell. Twenty-three participants were aged between 18 to 30 years (71.9%), while the remaining nine participants were aged 13 to 17 years (28.1%). Furthermore, twenty-seven participants (84.4%) possessed a bachelor's degree in information technology, while five (15.6%) were secondary school students learning biology. All participants were given consent forms at the beginning of the evaluation, in which they were asked to experience the ARCell three modules.

At the end of the evaluation, they must answer the questionnaire via a google form, which involves usability questions on usefulness, playfulness, ease of use, ease of learning. Others include satisfaction, aesthetics factor [28, 29], and open-ended questions in the final section. The usefulness aspect considers the users feeling on the application's helpfulness in understanding cells. Furthermore, the playfulness aspect tests the user experience using this application.

In fact, the ease of use facet determines the extent to which users feel about the simplicity of the application. The level of users in mastering this application is tested in the ease of learning aspect. Notably, user satisfaction is crucial to test their overall feeling of utilising the application. Lastly, aesthetics gathers the user's opinion on the application design, such as icons and colours.

Appendix 1 shows the interpretation of the mean score for the questionnaire results that shown in Table 1. The positive and negative aspects of the application were then collected at the end of the questionnaire from the respondents. Meanwhile, Table 2 shows the analysis of the positive and negative aspects of the questionnaire findings. Additionally, Cronbach's alpha was employed to measure the internal consistency or the consistency of an item in a group. The value of Cronbach's alpha approximating one signifies the item's significant internal consistency value.

Table 1 Mean Score Interpretation [30]

Mean score	Interpretation
1.00 - 1.80	Very Low
1.81 - 2.60	Low
2.61 - 3.20	Medium
3.21 - 4.20	High
4.21 - 5.00	Very High

Table 2 The Positive and Negative Aspects of the Application

Positive Aspects	Number	Negative Aspects	Number
Attractive and beautiful graphics	4	Insufficient topic content in the application	2
Realistic 3D model	5	Games are not challenging	6
Assist in the learning process	12	The application lacks audio feedback	2

Based on the results collected with the questionnaire, all items in all aspects were found reliable. This result is due to the value of Cronbach's alpha exceeding 0.7, indicating that this aspect is acceptable and reliable [31].

The majority of the average mean values for all aspects are more than four, and thus the users agree with all aspects of the application, which fall in the high category. Notably, the usefulness aspect received the most positive feedback with an average mean value of 4.12. In essence, the users approved the application to assist them in the learning process, confirming the subjective feedback shown in Table 2.

Digital natives born after 1980 could benefit from computerised games in an educational environment [32]. Previous research asserted that students labelled as "digital natives" are more comfortable using the latest technologies, namely computers, mobile phones, and the Internet, specifically for communication and information access [33]. Games in a learning environment are known as digital game-based learning. This concept incorporates learning information into existing digital games or following the learning objective [34]. [35] concluded that digital games enhance the students' course achievement while increasing their motivation towards the course. However, there is still a lack of research on DGBL, especially for AR technology.

This study created and studied an augmented reality game in an educational setting named ARCell. It provided the game element in the biology cell topic learning using augmented reality technology. The 3D models and the graphic design in the application can get the participants' attention. The result aligned with the previous research, indicating that these factors assisted their learning process and increased motivation [34]. At the same time, the games boost the student's motivation. Overall, the users think that the ARCell application can help students in the learning process with attractive graphics and realistic 3D modelling of cells. The result proved that the students are interested in the application and have positive attitudes for using these games to achieve learning objectives. The integration of education and fun has been reached.

However, some gamification with terrible designs might have a negative impact on student motivation and learning [36]. For instance, several factors have impacted the ARCell's performance, including insufficient topic content, poor audio feedback, and the straightforward nature of the game. At the initial stage, this feedback is expected as the developed ARCell was intended to determine the potential of the AR game concept. Therefore, not all topics were included in the application. Nevertheless, helpful feedback will significantly enhance the application and its future developments. Based on the feedback above, the users felt that the game was less challenging and lack of attractive game audio. Therefore, the mean value of the playfulness was lower than 4. Participants suggested that they would like the application to display more gaming elements, including different levels and cells with a unique ability.

Specifically, the cells have the mobility to slow down or freeze their movements and enter the bonus stage once it reaches certain conditions. Given these points, it is imperative to improve the ARCell application before executing the evaluation on a larger scale.

5. Conclusion

AR technology combined with the game concept in education has not yet been explored, where its challenges and benefits are still uncertain. In this study, the mobile AR application with a Fruit Ninja game-like concept was explored and developed as a learning tool to analyse cells in the biology subject. The application employed a quiz module to test their understanding, requiring users to select the correct AR marker/answer and place them on a quiz paper board. Accordingly, the application was developed using Unity and Vuforia as the central development platform. Overall, the results revealed the potential of integrating games and AR in education, where the teacher could utilise the application in the pedagogical approaches and entertainment. According to the participant's feedback, all usability factors were reasonable: usefulness, playfulness, ease of learning, ease of use, satisfaction, and aesthetics. Hence, this idea contributed to an improvement in the student's level of the learning experience.

For future works, this application should include extra content or topics on biology, as suggested by the respondents. Moreover, it should provide more game elements to increase the engagement level. One of the possible customisations is introducing an additional cell structure as a unique cell game element. This idea includes restoring life, slowing down the cell movement, and providing double scores in a certain period. Other concepts, such as board games, can also be considered. Cards utilised in the board game can be fitted with the AR technology, utilised as AR markers to visualise the 3D object, ultimately increasing the fun level. After carefully considering the feedback, we foresee that the outcome will be better and more applicable in classroom activities, especially as a supplemental teaching tool.

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Appendix 1 Usability Results

Construct		Mean ± SD	Cronbach's alpha	Mean score's interpretation
Usefulness		**4.12**	**0.71**	**High**
U1	This application is helpful in the process of learning biology subjects.	4.13 ± 0.61		
U2	This application gives me a sound understanding.	4.06 ± 0.72		
U3	The 3D object on the screen can be rotated, and the size can be altered as needed.	4.19 ± 0.59		
U4	Cell structure information will be displayed after I press the cell structure name.	4.16 ± 0.72		
U5	The quizzes in this application support the level of my understanding.	4.06 ± 0.72		
Playfulness		**3.90**	**0.71**	**High**
P1	When using this application, I did not realise the time had elapsed.	3.72 ± 0.46		
P2	When using this application, I am not aware of the environmental changes.	3.75 ± 0.44		
P3	This application brings me enjoyment in the learning process.	3.97 ± 0.69		
P4	This application stimulates my curiosity.	3.94 ± 0.62		
P5	This application arouses my imagination.	4.13 ± 0.61		
Easy to use		**4.01**	**0.76**	**High**
EU1	I can use this application easily without a written guide.	4.00 ± 0.57		
EU2	The content on the application is clear and easy to read.	4.16 ± 0.72		
EU3	I find this application easy to use.	4.03 ± 0.59		
EU4	It did not take substantial steps to achieve what I wanted to do.	3.94 ± 0.56		
EU5	I can interpret or understand the information, and the output is displayed readily.	3.91 ± 0.69		
Easy to Learn		**4.01**	**0.74**	**High**
EL1	I can master this application quickly.	4.09 ± 0.73		
EL2	I think the use of this application is easy to learn.	4.00 ± 0.72		
EL3	I can understand the functionality of this application quickly.	3.97 ± 0.59		
EL4	I can learn structure and function in animals and plant cells quickly.	3.97 ± 0.59		
EL5	I can remember how to use this application easily.	4.03 ± 0.47		
Satisfaction		**4.07**	**0.76**	**High**
S1	I am satisfied with this application.	4.13 ± 0.55		
S2	This application works as I expected.	3.91 ± 0.69		
S3	I think this application is interactive.	4.09 ± 0.64		
S4	I have fun using this application.	4.03 ± 0.69		
S5	I would recommend this application to a friend.	4.13 ± 0.66		
S6	I am satisfied with the 3D objects shown in this application.	4.13 ± 0.66		
Aesthetics		**4.04**	**0.73**	**High**
AE1	The design of the application interface looks attractive.	4.13 ± 0.55		
AE2	The colours used in this application are appropriate.	4.03 ± 0.69		
AE3	I am satisfied with the icons and images used in this application.	4.06 ± 0.72		
AE4	I can read the text content of the application clearly and easily.	4.06 ± 0.76		
AE5	I love the animation shown in this application.	3.94 ± 0.67		