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A Case Study on the Impact of Augmented Reality in STEM Education

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Abstract: *This study investigates the impact of Augmented Reality (AR) on STEM education by examining its influence on student engagement, comprehension, and motivation. Utilizing the AR 4 STEM mobile app for a theoretical Microbial Photosynthetic Electricity Generation (MPEG) STEM kit, 160 Malaysian secondary school students explored complex scientific concepts through interactive AR experiences. The technology facilitated hands-on learning, allowing students to visualize biochemical processes and bridge theoretical knowledge with real-world applications. Pre- and post-intervention surveys revealed significant improvements in students' interest, confidence, and understanding of STEM topics, underscoring AR's potential to enhance learning in challenging STEM domains. Despite these positive results, challenges related to device compatibility, and instructional clarity highlighted areas for further improvements. This research concludes that AR holds transformative potential for STEM education, offering a dynamic, interdisciplinary platform that fosters deep learning and sustained interest in science and technology fields.*

Keywords: STEM education, augmented reality (AR), learning outcomes, STEM Kit

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1. Introduction

Augmented reality (AR) is a fast-developing 3D technology that enhances users' sensory experiences by superimposing contextual information over the real world. Over the past ten years, augmented reality (AR) has garnered a lot of attention in the field of education, primarily due to the affordability of the handheld devices and major educational organizations like the Educause Learning Initiative and the New Media Consortium have recognized AR's potential (Ibáñez & Delgado-Kloos, 2018). This technology has special educational benefits, especially in STEM (science, technology, engineering, and mathematics) sectors, where it helps students in the development of spatial awareness, practical skills, and conceptual understanding (Bujak et al., 2013). Interest in AR's wider educational applications has also increased because of its immersive and interactive qualities, which promote more effective and interesting learning experiences (Cheng & Tsai, 2013; Rizov & Rizova, 2015). Although AR technology shows considerable potential, additional research is necessary to thoroughly explore its capabilities and mitigate its limitations within diverse educational environments, particularly during periods such as the COVID-19 pandemic, when the need for effective remote learning resources was heightened (Sanfilippo et al., 2022). Various attempts to establish a strong STEM education framework are underway in several Asian countries, especially in Malaysia. However, numerous challenges such as insufficient funding, cultural resistance, and mostly a decline in student curiosity and excitement toward STEM related subjects and activities hinders the efforts. This paper aims to explore the integration of AR technology in revitalizing STEM learning by enhancing student's engagement, confidence, and interest, making STEM education more appealing and accessible.

2. Problem Statement

Despite being acknowledged as an important part of today's education, STEM education has many obstacles that prevent it from being implemented successfully. One of the major challenges faced due to the lack of latest technologies integration in the STEM education. According to research by Hsu and Fang (2019), authors found that current STEM education frequently isolates technology from education, ignoring the difficulties that STEM fields face, such as waning students' enthusiasm. Lack of professional development and a shortage of competent teachers are other obstacles to the adoption of STEM education (Lee et al., 2018). The different viewpoints on the delivery methodologies of STEM also lead to ineffective strategies that lower students' enthusiasm and engagement (Margot & Kettler, 2019). Furthermore, there is still a gender gap in STEM education, especially in high-paying fields like computer science and engineering. According to authors (Lee et al., 2018), female's financial opportunities may be restricted in the event of choosing to pursue STEM areas due to stereotypes school of thoughts regarding female's aptitude for math and science.

According to Lee et al. (2018), developing integrated STEM classes that encourage students' creativity and collaborative problem-solving skills while maintaining or raising test results is another urgent concern. Lesson plans frequently feature various traditional didactic techniques, which makes it difficult for teachers to use interesting teaching techniques (Bagiati & Evangelou, 2015). STEM curriculum design, which involves creating technologically assisted modular engineering problems, must also consider students' interests and abilities (Lesseig et al., 2016). The assessment of STEM education has proved unsatisfactory in light of these interconnected issues.

As a results, this paper aims to explore the integration of immersive technology specifically on Augmented Reality (AR) in improving learning outcomes, motivation and student engagement in STEM related topics. This paper uses the STEM kit of microbial fuel cell poster integrated with AR 4 STEM phone applications to help create a creative and useful teaching and learning strategies in this STEM related field. The authors also have carried out a case study utilizing the STEM kit with AR 4 STEM application at a Malaysian National Secondary school with the participation of 160 school students. The findings from the case study were also presented in this paper.

3. Methodology

3.1. Development of the AR 4 STEM

The phone application of AR 4 STEM is an innovative educational tool developed to enhance learning experience of a Microbial Photosynthetic Electricity Generation (MPEG) STEM kit. The MPEG STEM kit developed to deliver STEM related knowledge such as biology, chemistry, and physics, specifically focusing on electricity generation from biochemical reactions. The poster of MPEG was designed to explain the functionality of MPEG and experimental setup guide of MPEG in an AR environment. Figure 1 depicts the explanation of MPEG's components and its' functionality.

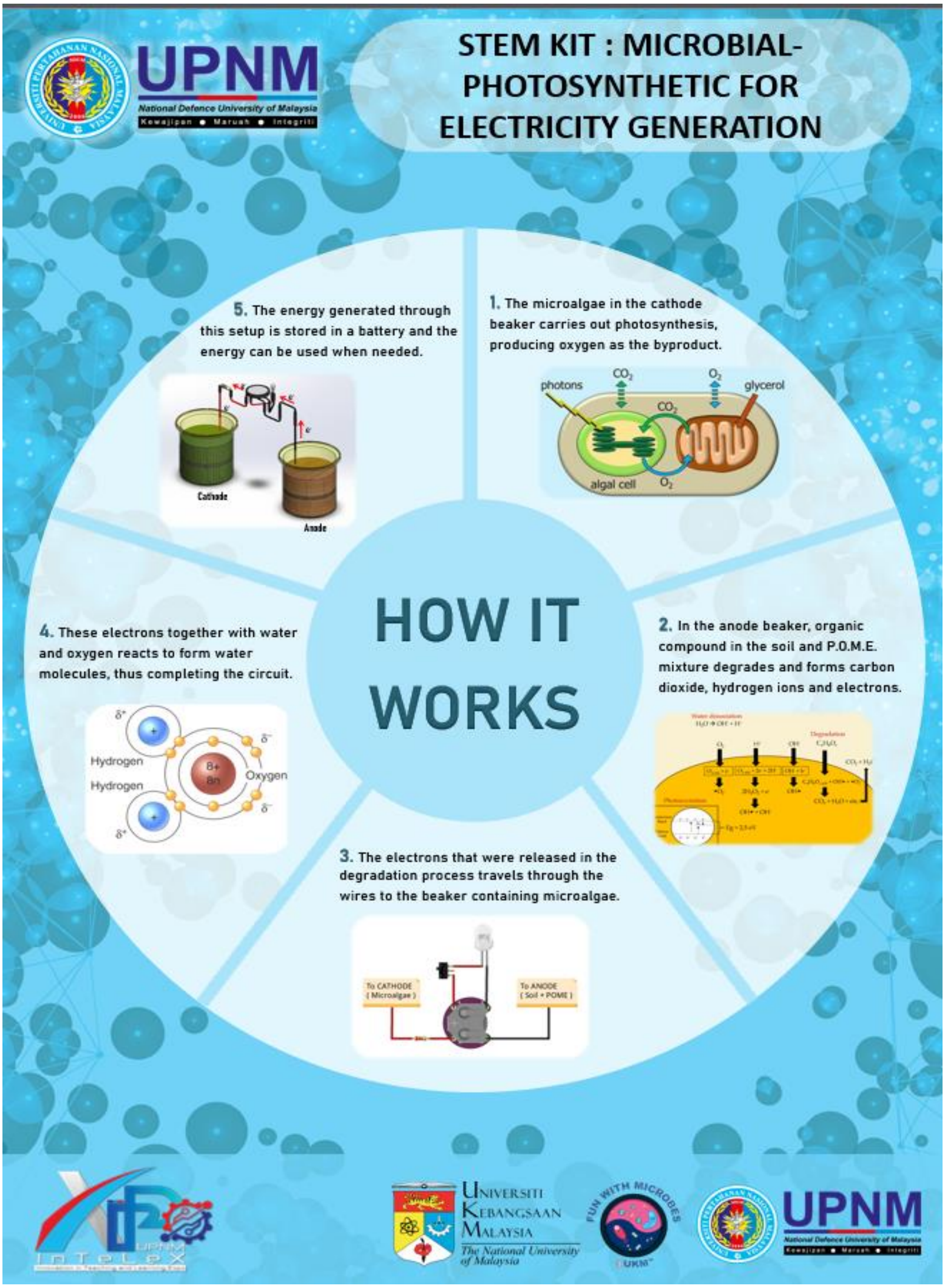

Figure 1: The Poster/Image explanation of MPEG STEM Kit's Functionality

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Figure 2 shows the experimental setup guide for the MPEG. The AR 4 STEM application then would be scanned upon these posters to learn more about STEM related knowledge of MPEG STEM Kit. Once the smart devices with pre-installed AR 4 STEM app is scanned, all the information on the poster/image animated alive in an AR environment, which authors believe would enhance the overall learning experience on STEM related topics. A user manual for the usage of this app and poster has been also developed in order to assist self-learning for any individuals utilizing the STEM kit complemented by the posters as in Figure 1 and Figure 2. The user manual has been also protected under the Malaysian Copyright Law with the number CRLY2024W00857.

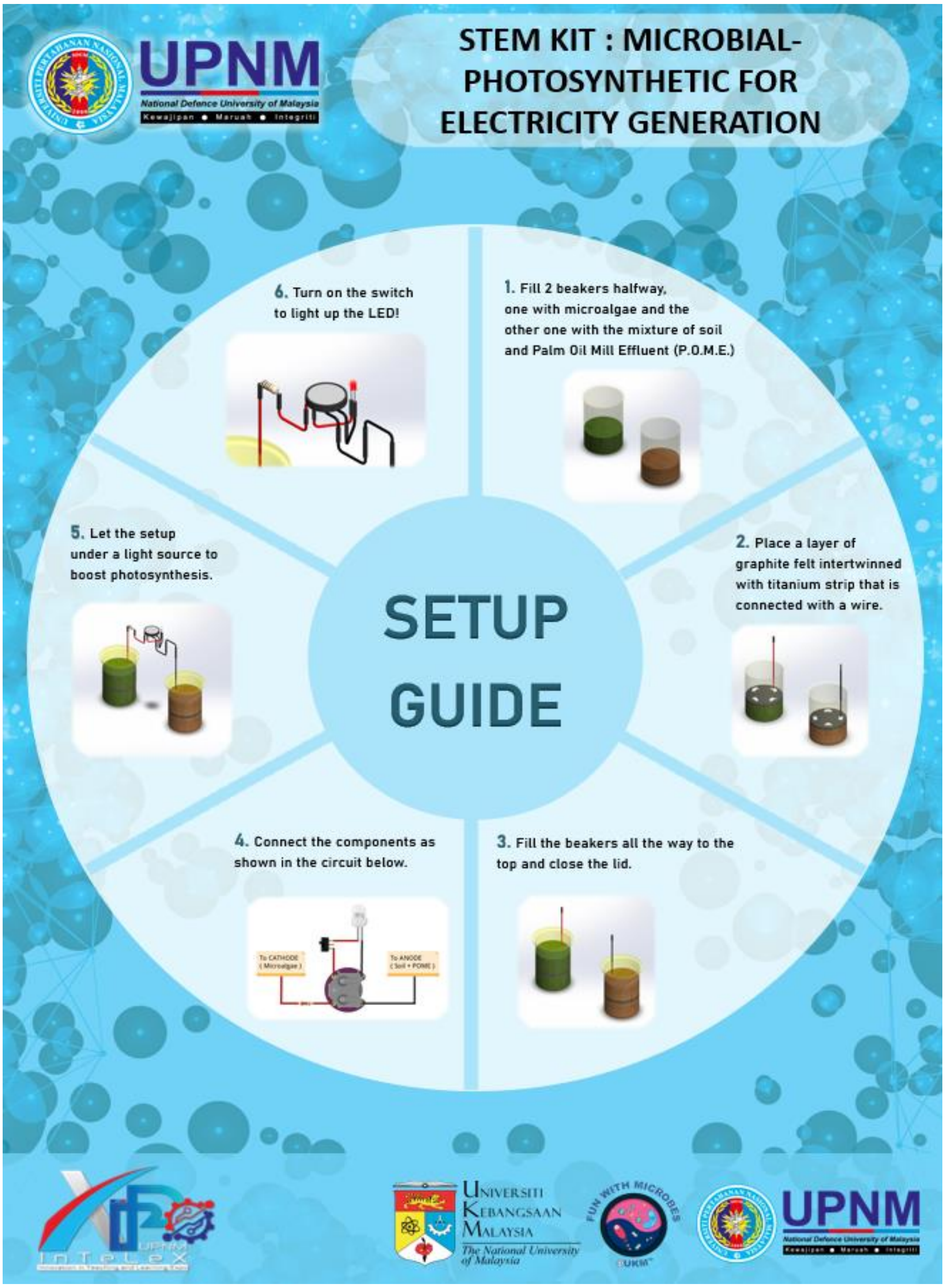

Figure 2: The MPEG STEM Kit's Setup Guide for an AR environment experiment

The AR 4 STEM app leverages on Unity3D, a powerful cross-platform game engine, and Vuforia, an augmented reality software development kit (SDK), to deliver a seamless AR experience on Android devices. Unity3D provides robust tools for developing interactive 3D applications, while Vuforia enhances AR functionality by enabling marker-based recognition and tracking. This integration ensures that AR 4 STEM delivers high-quality visuals and responsive interactions, essential for effective educational experiences. For the apps development, Vuforia Engine 10.17.4 and Unity 2022.3.8f1 were used for Augmented Reality functionalities and environment development. The application license key, obtained from Vuforia, was set up in the Unity inspector to integrate Unity and Vuforia Engine.

Several crucial sequences in the Unity environment were used in the development. Initially, an AR camera and an image target were used in the Component Scene to anchor the 3D model display in place of the Unity main camera. In order to help viewers navigate through the many STEM kit components, such as resistors and microalgae in a beaker, this scene also included a canvas with navigation buttons (Next, Previous, and Home). An interactive information button was located at the bottom centre of the screen, and the components were identified and positioned on the image target. When this button is selected, more details about elements like microalgae and palm oil mill effluent (POME) are displayed. A close button allows the user to close the information display. Figure 3 illustrates the development of the AR 4 STEM Kit, showcasing key components and features that enable interactive learning experiences in biology, chemistry, and physics.

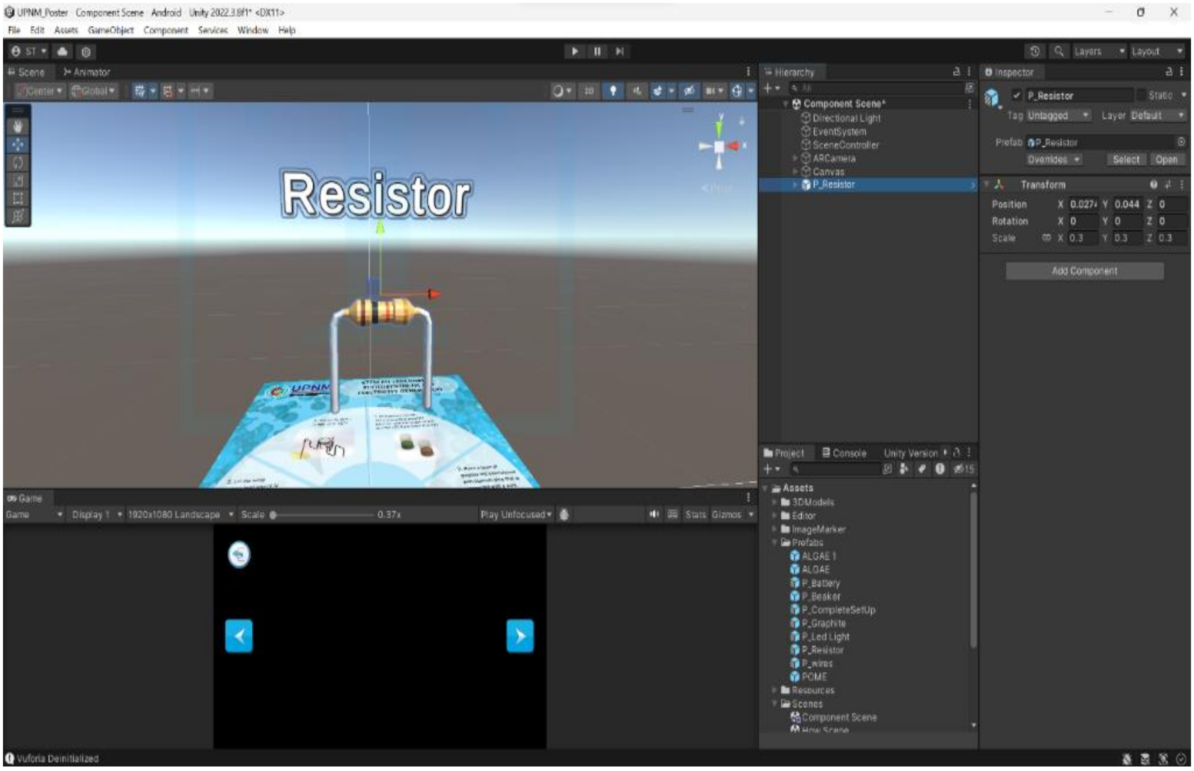

Figure 3: The development of component scene

In order to demonstrate the generation of electricity, the “How It Works” scene offers animated visuals of the movement of molecules within the biological reactions. An illustration of battery charging was also shown at the end of the animations, which depicted the motion of protons, electrons, carbon dioxide, oxygen, and water molecules. The main navigation point was the home scene, which displayed buttons labelled "Setup Guide", "How It Works?" and “Privacy and Policy" that led users to the experimental setup and assembly of the components and the overall functionality of MPEG STEM kit, respectively. Figure 4 shows the screenshot of the main home scene of the mobile apps, while Figure 5 illustrates the finalized and published AR 4 STEM apps in the Google Play Store.

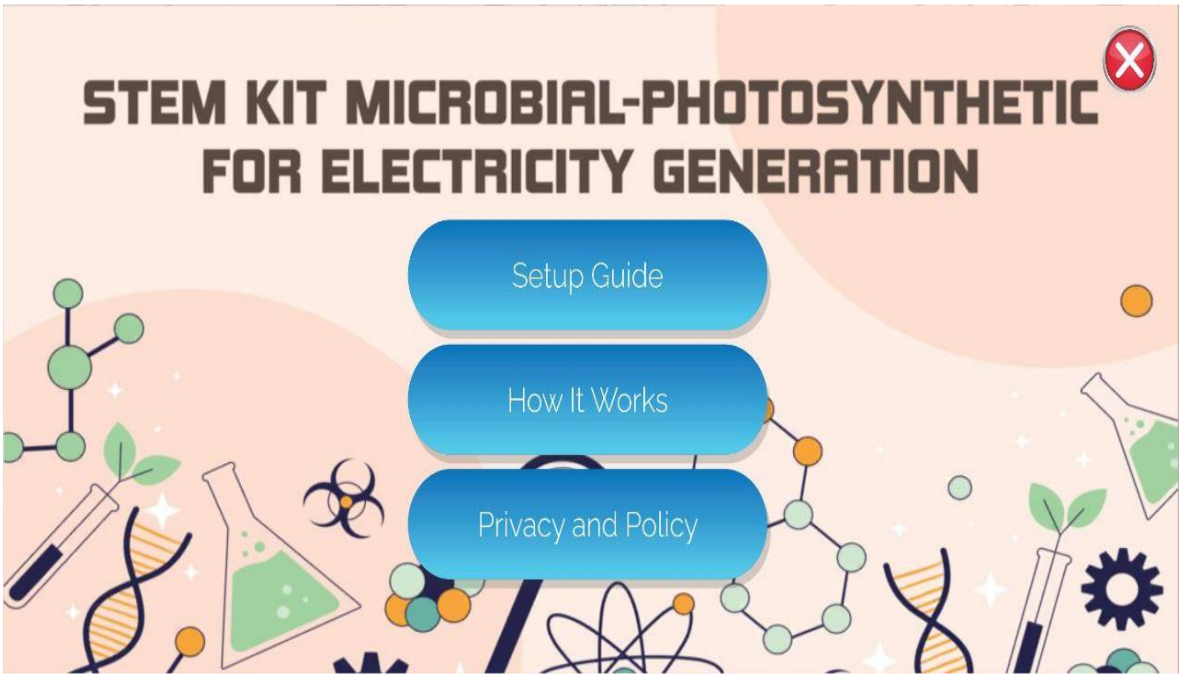

Figure 4: The Screenshot of AR 4 STEM apps's Main Page/Home Scene

Overall authors believe that the AR app represents a significant advancement in educational technology, particularly in the realm of STEM education. By combining augmented reality with the MPEG kit, this application offers a dynamic and engaging platform for students to explore the principles of biology, chemistry, and physics in electricity generation.

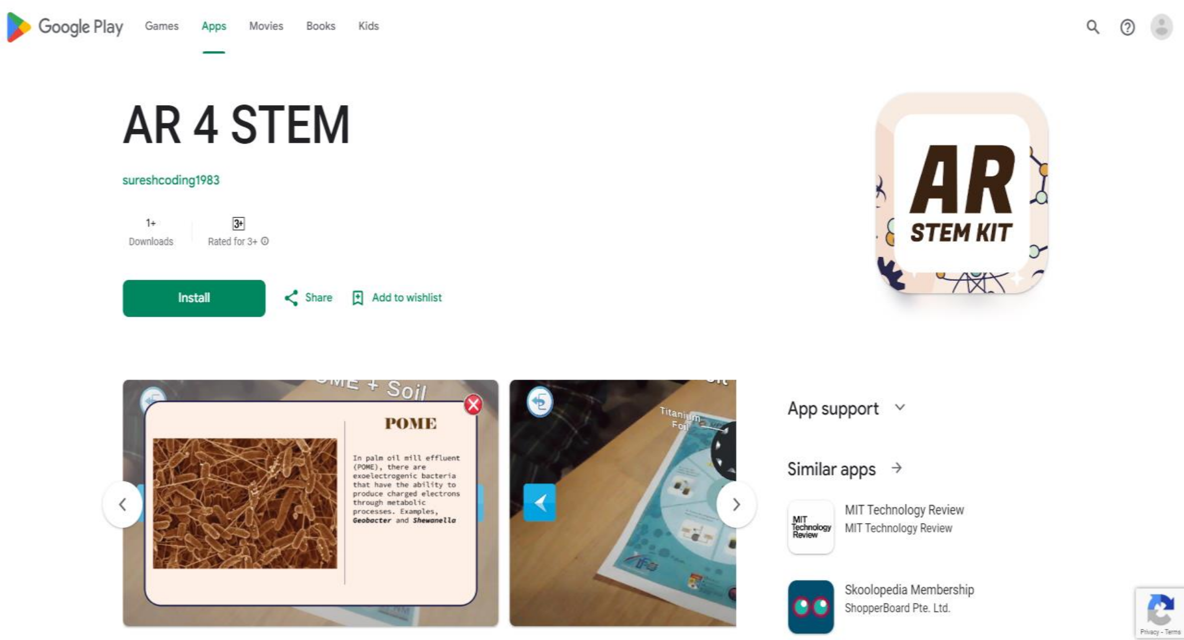

Figure 5: The Screenshot of AR 4 STEM apps's from Google PlayStore

3.2 Participants

The study included 160 high school students from W. Persekutuan, Malaysia's SMK Wangsa Maju Section 5. There were 92 female participants and 73 male participants, all aged 13, 14 and 16 years old. The pupils were split up into four sessions of forty students for each session. For this study, a designated of twenty facilitators among the students were trained a week prior to the STEM activities to assist the 160 students with the learning events. Students have to bring own respective smartphones under the BYOD programme (Bring Your Own Device) and download the relevant app from the play store in order to guarantee accessibility. In addition, few STEM teachers were in presence during the activities to assist the lessons and learn more about the experiences of the students using AR technology.

3.3 Procedures

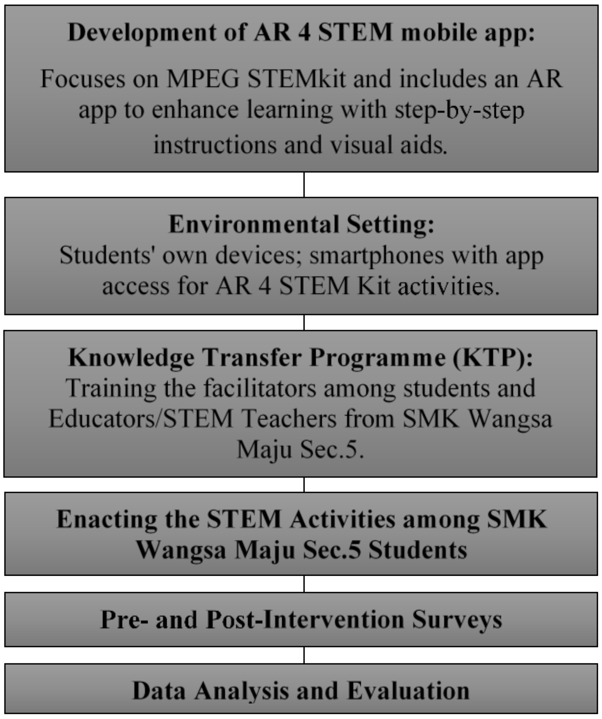

Figure 6: The Overall Flow of this Research Work

Figure 6 summarises the overall flow of this research work whereby the development of AR 4 STEM mobile applications starts with collaborations from various transdisciplinary research agencies from UPNM, UKM and with Cuber Lab Sdn. Bhd; an industry with the cutting-edge expertise for immersive technology. A week prior to the STEM event at SMK W.Maju Section 5, facilitators among the school students were trained together with the respective STEM teachers as an effort in empowering students through the Knowledge Transfer Programme (KTP) initiatives. During the STEM activities day, the students filled out a pre-survey prior to the interaction with the AR 4 STEM mobile apps, as a pre-intervention phase to gauge respective attitudes toward STEM subjects and the baseline of understanding on microbial fuel cells, and MPEG. This preliminary survey provides information about students' preexisting knowledge and viewpoints on STEM related subjects.

During the intervention phase, students were split up into eight groups with each 5 members and assisted by minimum 2 facilitators for each group for the assembling of the AR 4 STEM Kit's microbial fuel cell (MPEG). Students were encouraged to experiment with the app's features, and the augmented reality (AR) app which offered detailed explanations and visual aids. As a final phase of each STEM session students completed a post-intervention survey after the MPEG experiment, to assess students overall educational experience, comprehension of microbial fuel cells (MPEG), and any shifts in perspectives toward STEM fields. During the STEM event, facilitators also asked questions related to STEM on MPEG and hands over stationaries as gift to reward the excellent students to encourage more participation from the students.

In the final stage of data analysis, the researchers used statistical techniques to examine the information gathered from the pre-and post-surveys. The purpose of this analysis was to ascertain the effectiveness of the AR 4 STEM Kit towards the students' learning outcomes and attitudes toward STEM, providing insights on the impact of incorporating AR technology into the STEM's classroom works.

3.4 The AR Lessons

Figure 7 illustrates the STEM activities conducted with the facilitators and students of SMK Wangsa Maju Sec.5. Based on Figure 7, one can perceive the overall AR lessons experience for MPEG using the AR 4 STEM mobile applications were well received by the students and facilitators.

Figure 7: Collections of Pictures during the STEM activities

The MPEG (Microbial-fuel Photosynthesis for Electricity Generation) STEM kit incorporated with AR 4 STEM mobile applications aims to improve users' comprehension of sustainable science and technology mainly on STEM education. The MPEG STEM kit utilizes microbial activity to convert chemical energy from biomass into electrical power, presenting a potential approach to sustainable energy generation. Anaerobic bacteria in the biomass act as the anode in an MPEG, oxidizing nearby materials and releasing electrons. Energy capture is made possible by the transmission of some of these electrons to an oxygen-rich cathode environment, while the remaining electrons are utilized by bacterial cells (Kempa, n.d.).

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Using an experimental setup that comprises microalgae in the cathode chamber and anaerobic microorganisms in the anode chamber, the AR 4 STEM app illustrates this process in an interactive AR experiment environment. LED can be powered by the electricity generated by this system, providing a tangible and engaging illustration of sustainable energy production. The package encourages teamwork, critical thinking, and engagement with sustainable energy concepts by combining biology, chemistry, and environmental science to facilitate interdisciplinary learning. Figure 8 summarises the experimental setup and the interactive biochemical reactions in the AR environment from the viewpoint of the AR 4 STEM mobile applications user.

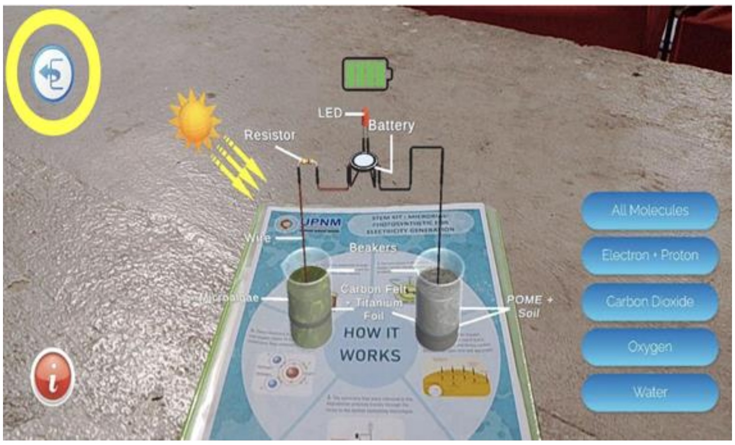

Figure 8: Experimental Setup in AR environment

3.5 Questionnaire

Students were invited to answer a questionnaire intended to record the user's experience after completing the Augmented Reality (AR) lessons. The Baseline Assessment was carried out prior to the introduction of the AR 4 STEM mobile apps, while the Post-AR Implementation Assessment, were done right after the introduction of the mobile apps, and the Comparative Questions section comprised the three sections of this questionnaire. The five Likert-type items in the Baseline and Post-AR Implementation sections were identical and were designed to assess students' viewpoints both before and after AR technology was introduced.

The purpose of these questions was to evaluate the impact of AR on students' interest and participation in STEM education. Three questions made up the Comparative Questions segment, which sought to determine students' opinions about the use of AR in STEM education as well as respective preferences between conventional teaching techniques and with the AR approach. The Cronbach's alpha was used to determine the reliability of internal consistency. The questionnaires were designed impartially and thoroughly and covered the whole range of potential student answers by adhering to Stone's (1993) recommendations for effective questionnaire design. Prior to the STEM event, the questionnaire was piloted to improve its relevance and clarity to further fortify the design.

An open-ended question was also introduced to allow the students to share general opinions regarding the AR lessons. This paper aims to investigate the impact of augmented reality technology in students' enthusiasm and perceptions on STEM teaching methodologies. The approach aligns with other studies, such as Chang et al. (2010) and Gulikers et al. (2006), that examined ideas like motivation, authenticity, and engagement using structured items. Variances among the items (ranges from 0.50 to 0.74 as shown in Table 1) and the reliability analysis confirms that the questionnaire collects valid and consistent data as intended by the authors. One can conclude that from Table 1, the questionnaires prepared and surveyed has overall moderate reliability.

Table 1: Reliability of questionnaire (Cronbach's alpha)

Questionnaire Section	Baseline Assessment	Post-AR Implementation	Comparative Questions
Interest in STEM	0.74	0.67	0.73
Confidence in STEM	0.73	0.63	-
Engagement with STEM	0.60	0.74	-
Understanding of STEM concepts	0.72	0.70	0.58
Effectiveness of STEM teaching methods	0.56	0.49	0.51
Total reliability	**0.67**	**0.65**	**0.61**

4. Results and Discussion

Authors in this paper have explored the students' perception on STEM subjects before and after implementation of augmented reality (AR) technology, using Kendall's W coefficient to assess the consistency in students' ratings. Descriptive and inferential statistics highlight shifts in interest, understanding, confidence, engagement, and perceived effectiveness.

Referring to Table 2, from the baseline assessment before implementing Augmented Reality (AR), students displayed moderate levels of interest (M = 3.83) and confidence (M = 3.16) in STEM subjects. Engagement was relatively high (M = 3.73); while understanding (M = 3.60) and perceived teaching effectiveness (M = 3.70) were also at moderate levels. After the introduction of AR, there was a significant increase in students' interest in STEM (M = 4.25), alongside improved respective students' confidence (M = 3.67) and understanding (M = 4.08). Students rated the effectiveness of AR-enhanced teaching methods highly (M = 4.23), although engagement saw a slight decrease (M = 3.40). In comparisons between AR-based learning and traditional methods, students found AR to be more engaging (M = 4.12) and reported enhanced understanding (M = 4.09). Authors can conclude based on results from Table 2, there was a strong preference for the continued use of AR in STEM classes (M = 4.13).

Referring to Table 3, significant changes were observed in students' interest, confidence, and understanding from baseline to post-AR conditions, with Kendall's W indicating a notable improvement in agreement among students' responses. For instance, students' interest scores significantly increased from baseline to post-AR ($\chi^2 = 456.95$, df = 5, $p < 0.001$).

Table 2: Summary of students' perceptions of the AR lessons

	Item	Mean	Standard deviation
Baseline Assessment	How interested are you in STEM subjects (Science, Technology, Engineering, Mathematics)?	3.83	0.86
	How confident are you in your ability to succeed in STEM subjects?	3.16	0.85
	How often do you find STEM subjects engaging and enjoyable?	3.73	0.77
	How well do you understand the concepts taught in your STEM classes?	3.60	0.85
	How effective do you find the current teaching methods for STEM subjects?	3.70	0.75
Post-AR Implementation	How interested are you in STEM subjects after using AR technology?	4.25	0.82
	How confident are you in your ability to succeed in STEM subjects after using AR technology?	3.67	0.79

	How often do you find STEM subjects engaging and enjoyable after using AR technology?	3.40	0.86
	How well do you understand the concepts taught in your STEM classes after using AR technology?	4.08	0.84
	How effective do you find the teaching methods for STEM subjects after using AR technology?	4.23	0.70
Comparative Questions	Do you think AR technology has made learning STEM subjects more engaging compared to traditional methods?	4.12	0.71
	Do you think AR technology has improved your understanding of STEM concepts compared to traditional methods?	4.09	0.76
	Would you prefer to continue using AR technology in your STEM classes?	4.13	0.86
Total		**3.89**	**0.80**

In addition, the comparative analysis ($\chi^2 = 327.75$, df = 3, $p < 0.001$) from Table 3 demonstrated that AR technology significantly outperformed traditional methods in terms of fostering interest and understanding. The value of W rises to 0.57 during the Post-AR in comparison to baseline value shows improved agreement compared to the Baseline.

Table 3: Summary of Kendall's W test on students' perceptions of the AR lessons

Item	**Constructs**	**Mean**	**SD**	**Mean rank**	***W***	***X²***	***df***	***p***	**Post hoc**
Baseline	Interest	3.83	0.86	3.43	0.53	420.743	5	<0.001	
	Confidence	3.16	0.85	2.27					
	Engagement	3.74	0.77	3.23					
	Understanding	3.60	0.85	3.03					
	Effectiveness	3.70	0.75	3.13					
Post-AR	Interest	4.25	0.82	3.45	0.57	456.95	5	<0.001	Post > Base (p < 0.001)
	Confidence	3.67	0.79	2.27					
	Engagement	3.40	0.86	2.96					
	Understanding	4.08	0.84	3.08					
	Effectiveness	4.23	0.70	3.36					
Comparative	Interest	4.13	0.86	2.06	0.68	327.75	3	<0.001	Inter > Under, Effec (p < 0.001)
	Understanding	4.09	0.76	1.99					
	Effectiveness	4.12	0.71	2.03					

Note: In the post hoc column, Post means Post-AR Implementation, Base means Baseline Assessment, Inter means Interest, Under means understanding, and Effect means effectivenesss.

On the other hand, the post hoc analysis shows that Interest scores are significantly greater than Understanding and Effectiveness, highlighting that while all constructs are positively rated, Interest stands out the most proving the usage of AR technology increases the interests among the students in learning STEM subjects.

In addition, students' feedback was also gathered through the open-ended questions section and students had given respective feedback on AR learning experiences which has highlighted several advantages, such as the improvement of complicated concept visualization, interactivity, and real-world applicability. Plenty of students mentioned that AR technology successfully makes abstract ideas come to life. AR makes difficult subjects more understandable and interesting by producing 3D representations of processes, including molecular motions or detailed experiment instructions. AR helps the students to better understand concepts that could otherwise be challenging to understand by visualizing complicated ideas.

Students highly appreciated the immersive and dynamic nature of AR-based lessons, which maintained students' motivation and engagement by allowing the students to interact with virtual objects and explore STEM topics in a hands-on, immersive environment. This interactive instructional approach enhanced student engagement and interest in the content. Additionally, many students noted that AR technology facilitated connections across various STEM disciplines. By overlaying virtual information onto real-world elements, AR enabled students to understand the interconnectedness of different scientific fields, fostering a more integrated comprehension of STEM subjects. This interdisciplinary practical applications approach made learning experiences more relevant, as students could visualize relationships between scientific concepts to real-world scenarios, heightening the relevance and significance of the lessons and encouraging greater interest in STEM subjects.

While students responded positively to AR-based learning, some encountered issues with internet connectivity and device compatibility, suggesting that enhancing compatibility and optimizing performance across network conditions could improve accessibility. Additionally, students noted that some instructional content in AR applications was overly complex or unclear; simplifying language and adding supporting materials may enhance AR's utility as an instructional tool. Although initially drawn by AR's novelty, students expressed concerns about sustaining engagement in longer sessions. Incorporating interactive exercises or gamified features could help maintain focus and maximize learning outcomes. Overall, students regarded AR as a transformative tool for STEM education, appreciating its dynamic, immersive, and visual nature. With ongoing advancements in accessibility, instructional clarity, and engagement strategies, augmented reality shows significant potential to enrich STEM learning and inspire a new generation of learners.

5. Conclusions

In conclusion from the study conducted, authors believe by incorporating Augmented Reality (AR) into STEM education can significantly boost student engagement, comprehension, and enthusiasm for subjects often perceived as challenging. The study also shows that tools like the AR 4 STEM apps enhance students' understanding of scientific concepts by connecting theoretical knowledge to practical applications, such as through interactive visualizations of complex biochemical processes.

However, AR implementation faces challenges like high costs, technical issues, and the need for effective teacher training. Addressing these barriers could further unlock AR's potential as a powerful educational tool. Future research should explore scalable solutions to these challenges and evaluate AR's long-term impact on learning outcomes. Authors believe that ultimately, AR holds promise for transforming STEM education by making science more accessible, engaging, and relevant, potentially inspiring a new generation to pursue careers in science and technology fields.

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