Mobile Augmented Reality on Electric Circuits for Science Learning in Primary School Students: The User Experience Evaluation

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Abstract
The adoption of mobile augmented reality (AR) technology has expanded in various ways. It can be utilized, especially in education, which is a crucial instrument used in the learning management process and helps change the perspective about education, including activities in the laboratory. This research aimed to evaluate the level of user experience among 6th-grade students toward augmented reality on electric circuits for science learning. The participants were 28 6th-grade students in the Northeastern region of Thailand. This study used a pre-experimental design involving a single-group post-test-only design. An AR app was developed based on the misconceptions and provided features related to learning standards and indicators of the national curriculum; moreover, AR app showed things that the naked eye cannot see, making them visible. The participants evaluated their user experience through twenty-six items of the user experience questionnaire. The finding found that attractiveness, dependability, and novelty dimension rated at an “excellent” level. In addition, perspicuity and stimulation were above average, demonstrating that our AR app performed well and received favorable responses.

Keywords: Mobile Augmented Reality, Electric Circuits, User Experience, Primary School Students

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1. Introduction

The current technological advances are always creating chances for new strategies to promote creative methods to facilitate learning (Omair et al., 2022). One popular digital technology is augmented reality (AR), a rapidly evolving state-of-the-art. Can seamlessly integrate virtual objects into the real world, creating a truly immersive experience (Akçayır & Akçayır, 2017). AR displays animation, three-dimensional (3-D) graphics, and video through handheld devices. Furthermore, AR users expressed high levels of motivation and satisfaction while interacting with the technology due to AR as a practical learning tool being easily accessible, portable, and affordable, allowing users to access models from any device at any time, and it promoted curiosity and engagement in the learning process (Chookaew et al., 2018). Nowadays, AR is used widely in learning science. As abstract concepts frequently explain natural phenomena in science courses, incorporating technology has become essential to support these subjects. To enrich students' learning environments, especially when dealing with complex and abstract concepts (Anil & Batdi, 2023). Sahin and Yilmaz (2020) explored the influence of AR in science learning on students' attitudes and academic achievements. The findings indicated that using this technology positively affected students' attitudes and contributed to enhance academic performance. It suggested that pupils preferred using AR in the science learning because AR helped them see the concept more concretely.

Many students frequently see physics as a complicated and uninteresting subject because of its complex and highly abstract concepts (Mbonyiryivuze et al., 2022). Past studies found that students frequently have misconceptions about a current running through the circuit when the switch shuts and the resistance magnitude based on the electric current (Nugraha et al., 2018). These concepts related to the knowledge of voltage, current, and resistance due to their abstract nature and difficulty explaining. Understanding how these three variables interact within a circuit is consistently tricky and challenging for experiments in a natural laboratory (Avilés & Cruz, 2017). Moreover, while performing electrical circuit experiments in schools, teachers must supervise students to construct accurate circuits and avoid hazardous ones like short circuits. However, it was unfeasible to thoroughly monitor each student's circuit in larger classes, which may cause harm. It required substantial time and effort to maintain experiment equipment and prepared equipment for potential fallibility during experiments in a laboratory (Kuriki et al., 2021).

The study emphasized a mobile augmented reality of electric circuits for primary school students. This AR app allowed students to experience and interact with 3D virtual objects of the abstract topic. This research aimed to evaluate the level of user experience among primary school students towards augmented reality.

2. Literature Review

2.1 The Concept of Augmented Reality (AR)

AR technology creates an interactive experience by merging the real and virtual worlds (Marini et al., 2022). This technology allows the visualization of the actual environment through the application implemented by computer-generated such as pictures, videos, sound, or various parameters that can be added to our real-world environs with overlay physical objects in real-time. Users can become fully immersed in a generated virtual environment. Moreover, it enables users to interact with and observe 2-D or 3-D data in the real world (Suhaimi et al., 2022). However, AR cannot replace physical reality. On the other hand, they can add new experiences and layers on top of the reality world, which is confirmed by utilizing mobile devices and cameras to broaden the reach of the natural world (Mukhtarkyzy et al., 2022). Therefore, AR technology is suitable for younger age groups as it does not rely on a mouse and keyboard to reach the generated virtual environment (Esmaeil et al., 2023).

2.2 Augmented Reality in Science Education

AR technology provides numerous chances to develop instruction and learning encounters (Mukhtarkyzy et al., 2022). In a past study, Irwanto et al. (2022) addressed trends in the use of AR in science learning reported from the Scopus database for the last 15 years (2007-2022) that AR has been used widely at all levels of education. Because it is a technology that can interact with various learning styles, it can operate on multiple devices, including tablets, smartphones, and laptops. It also can stimulate interest, increase motivation to learn, increase understanding of abstract concepts and help strengthen the efficiency of learning science management. It supports students to have a positive attitude toward learning good science, enhancing students' learning experience and encouraging a creative new learning environment (Yilmaz, 2021).

Furthermore, researchers also mentioned the use of AR in elementary students. From the previous study, Volioti et al. (2022) developed an augmented reality application system for teaching physics for grades K–12 in schools. The study revealed positive results, indicating user-friendliness; additionally, it was a system that helped to enhance learning and to achieve intended learning objectives.

One of the benefits of utilizing AR in learning about electrical circuits for elementary students was an interest-generating tool which motivated participation in learning. It was also a dynamic technology that helped to transform abstract concepts into concrete that is impossible through laboratory equipment. It assisted students to learn individually and freely through the interaction with technology media. It helped them learn and surpass the limitations of lacking laboratory equipment (Baran et al., 2020).

2.3 Usability Testing

Usability Testing is a crucial factor in assessing the quality of mobile applications, measuring both the ease of use and user satisfaction with their functionality, which will help applications function efficiently and offer a pleasant experience (Szekely et al., 2023). Furthermore, the User Experience (UE) connects with the method the user perceives when interacting with the system, a crucial element in the system's development (Ramli et al., 2023).

Users can evaluate the usability testing of mobile applications through the User Experience Questionnaire (UEQ) for the development of an efficient system.

The UEQ is an efficient instrument or questionnaire used to assess the UE designed for immediate, spontaneous responses, given the importance of swift evaluation (Silva et al., 2023). Laugwitz et al. (2008) developed UEQ that the UEQ scale structure includes six scales containing 26 pairs of opposite adjectives about the application's characteristics, namely Attractiveness (enjoyable, good, pleasing, pleasant, attractive, and friendly), Efficiency (fast, efficient, practical, and organized), Perspicuity (understandable, easy to learn, easy, and straightforward), Dependability (predictable, supportive, secure, and meets expectations), Stimulation (valuable, exciting, engaging, and motivating), and Novelty (creative, inventive, leading edge, and innovation). These questions could be scored on a 7-scale, ranging from -3 (worst) to +3 (very good).

3. Methodology

3.1 Study Participants

The participants in this research were twenty-eight sixth-grade students from the Northeastern part of Thailand. here were 14 females (50%) and 14 males (50%) aged 12. They needed to gain experience in utilizing augmented reality for science learning.

3.2 Learning Materials

We developed mobile augmented reality and designated “Bright Circuits AR” for primary school students. The AR app was built for science learning of electric circuits, which followed the learning standards and indicators of the national curriculum as follows: 1) to identify the components and describe the functions of each component of a simple electrical circuit from empirical evidence, 2) to create a diagram and assemble a simple electrical circuit and 3) to design an experiment and conduct it using an appropriate method to explain the procedure and results of connecting electric cells in series and parallel.

The Bright Circuits AR app, developed as marker-based AR, was categorized into three sections: electric devices, series electric circuits, and parallel electric circuits.

Figure 1: An example screenshot from the Bright Circuits AR app: A) the initial screen, B) the interaction topics screen.

The initial screen on the Bright Circuits AR application as shown in Figure 1A, consisted of four sections: (i) Scan AR area, (ii) Marker for scan AR, (iii) Contact information for assistance (Facebook, Line, Phone, and E-Mail), and (iv) The instructions of the Bright Circuits AR application after selecting components of Scan AR. The screen displays three topics to interact with AR: electric devices, series electric circuits, and parallel electric circuits, as shown in Figure 1B.

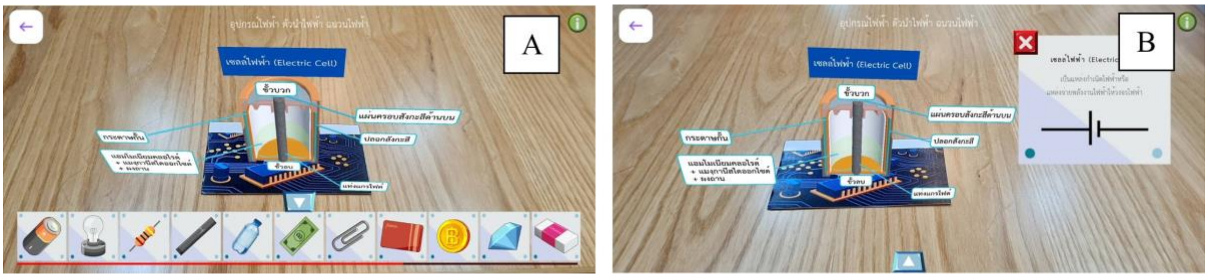

Figure 2: An example screenshot from the Bright Circuits AR app on the electric devices section: A) 3D displaying results, where students were able to select and study one electrical component of their interest at a time, B) displaying the results of function "i" icon will which presenting additional data for that electrical device.

The participants used their mobile devices to scan the electric device marker, which is the first topic. They can select each type of electric device, including insulators and conductors. Who are interested in studying information, as depicted in Figure 2A. Furthermore, various devices showed the information about names, duties, electrical symbols, and components by displaying results in 3D, as in Figure 2B, before moving to the next topic.

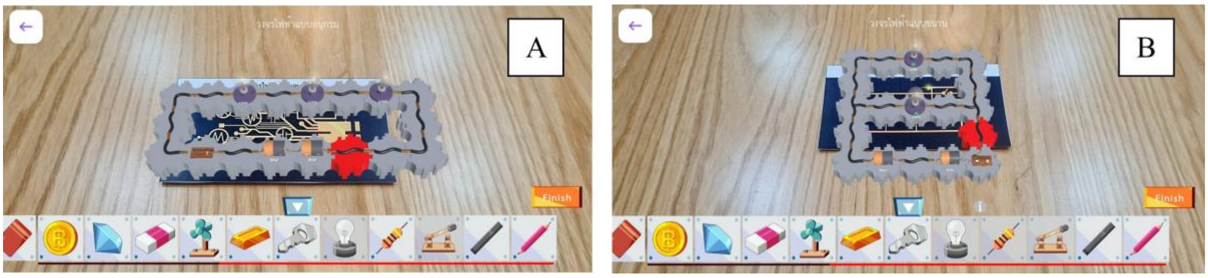

Figure 3: An example screenshot from the Bright Circuits AR app on the series electric circuits and parallel electric circuits section: A) presenting 3D visuals in the section on connecting electrical circuits in series, B) presenting 3D visuals in the section on connecting electrical circuits in parallel.

In the next topic, the tasks were connecting series electric circuits and parallel electric circuits. In the first step, the participants used their mobile devices to scan the series electric circuits marker or parallel electric circuits marker to interact with AR. When the scan succeeded, the system displayed 3D jigsaw puzzles, in which the users could choose a jigsaw to place electric devices to build the correctness of electric circuits. Users could select the finish button if they were confident in creating an electric circuit, as shown in Figure 3A and Figure 3B. After that, the user could use the edit button when to update an electric circuit. The application displayed the outcomes after choosing the finish button.

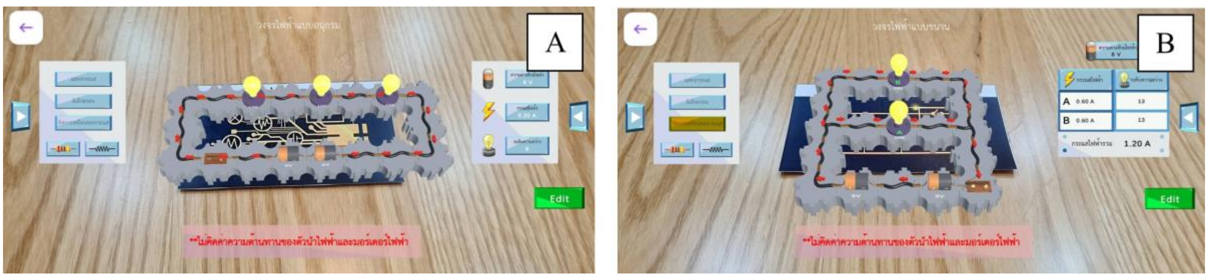

Figure 4: An accurate and complete of 3D display representation:
A) The complete results of connecting electrical circuits in series and
B) The complete results of connecting electrical circuits in parallel.

When choosing the finish button, the system displayed accurate outcomes by presenting voltage, current, and brightness levels on the right side of the screen. Additionally, on the left side of the screen, there was a button display to visualize the direction of current flow and electron flow. Also, there was an electrical symbol button to display the circuit as an electrical symbol, as shown in Figure 4A and Figure 4B.

3.3 Data Collection

This study employed a pre-experimental design involving a single-group post-test-only design. Figure 5 presented experimental procedures; the participants were 28 6th-grade students in the Northeast, Thailand. Before interacting with the Bright Circuits AR, the first author briefly introduced this AR app for 20 minutes in the following manner: What is the Bright Circuits AR app? How does it work? Then, the participants were assigned to interact through three tasks according to three sections of the AR app for 120 minutes as follows:

1) Do you know about electric devices, conductors, and electrical insulators? To learn to get this information to apply to connect electrical circuits.
2) How can you connect electrical circuits in series to make the light bulb shine the brightest? To design and choose electrical devices, conductors, or electrical insulators to connect to succeed the mission.
3) How can you connect electrical circuits in parallel to make both light bulbs light up simultaneously, and with the condition that if one bulb removed from the circuit, the other bulb must remain lit?

For the accomplishment of the mission, it involved designing and selecting electrical components, conductors, or insulators for connection. After completing the mission, students would complete questionnaires regarding their proficiency in utilizing augmented reality technology for 10 minutes.

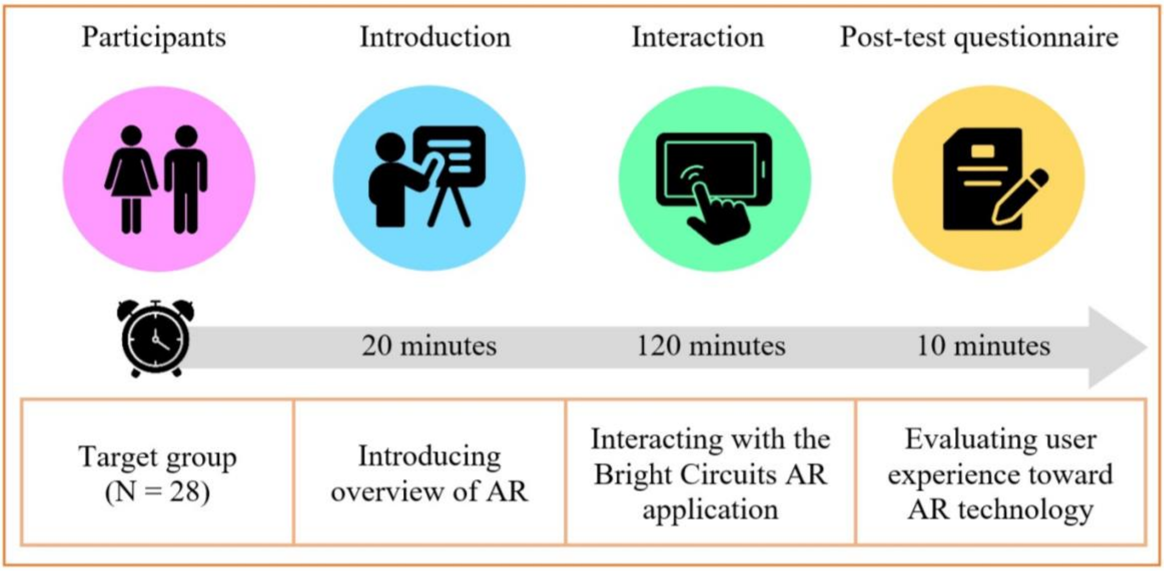

Figure 5: Experimental design.

3.4 Data Analysis

This study used Use Experience Questionnaire (UEQ) questionnaires adopted from Kusumaningshi et al. (2022). The UEQ was reliable and valid (Laugwitz et al., 2008) to measure the quality of the interactive AR app that had twenty-six items and consisted of six scales: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty with the positive term and the negative term. There was a 7-stage scale from –3 to +3: -3 was the most negative answer, 0 was the neutral answer, and +3 was the most positive answer. Mean was used to analyze the UEQ to compare with benchmarks that classified into five categories per scale: excellent, good, above average, below average, and bad.

4. Results and Discussion

4.1 Results

Figure 6 displays the mean outcomes for every UEQ evaluation scale (depicted in vertical bars) and their variability (represented in black lines atop the vertical bars). Perspicuity and stimulation yielded the least favorable outcomes. Most participants declared that there was some confusion in downloading the app. In addition, some students needed clarification of the app instructions.

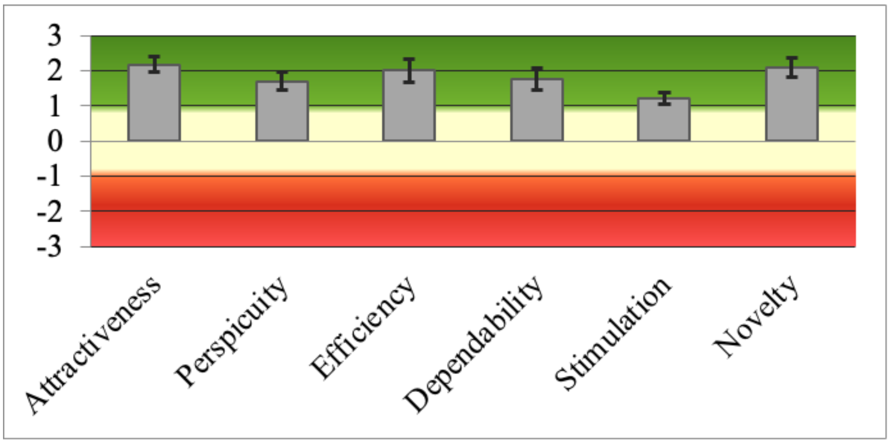

Figure 6: Mean and variance of each scale.

The findings from AR app assessment compared with the benchmark data provided in the Data Analysis Tool from the website (www.ueq-online.org). Figure 7 illustrates that four scales which were excellent comprised of attractiveness (M = 2.18, SD = 0.61), efficiency (M = 2.01, 0.91), dependability (M = 1.76, SD = 0.84), and novelty (M = 2.08, SD = 0.75). However, perspicuity (M = 1.70, SD = 0.69) and stimulation (M = 1.21, SD = 0.45) were above average.

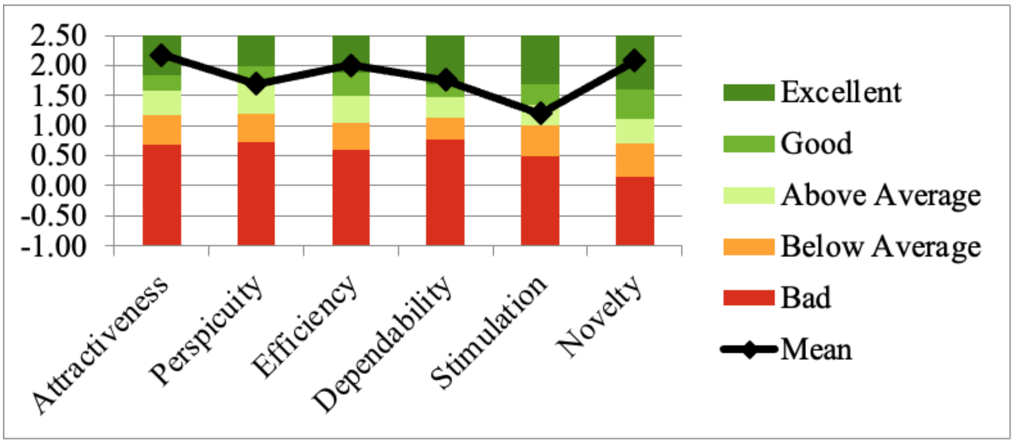

Figure 7: Comparison of the data with the benchmark.

4.2 Discussion

The research findings correlated with Mercier et al. (2023) on the web AR application for evaluating the impact of geolocation data on usability through UEQ. Their findings found that the overall usability of their system was excellent. Moreover, our results related to the work of Kusumaningsih et al. (2022) on the AR development for solar system application for elementary school students and the application evaluation. They used UEQ to measure students' experience towards AR, to which students responded positively as the overall resutls of the Bright Circuits AR. These intriguing findings closely aligned with previous studies that conducted a user experience of VR through the UEQ, in which the attractiveness, dependability, and novelty dimensions were rated at an "excellent" level (Borgnis et al., 2021). This AR app was enjoyable, creative, predictable, fast processing, efficient, practical, attractive, and friendly. On the other hand, perspicuity and stimulation dimensions need to be improved in AR apps to simplify usage and encourage users to use AR apps.

5. Conclusions and Suggestions

The outcomes of this study are highly encouraging and captivating in terms of user engagement with Bright Circuits AR. Most students felt the enjoyment. Moreover, they expressed that AR was practical, implemented, and contemporary. In our future work, we will improve the system for more user-responsive learning experiences, streamlined functionality, increased engagement, and adaptation for Android and iOS operating systems.

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