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Usability analysis of marker-based augmented reality application for the microcontroller study

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ABSTRACT

Virtual labs using augmented reality (AR) applications have brought transformation in teaching laboratory courses. However, in the field of engineering laboratories, the use of AR applications is still new. In this work, a marker-based AR application is used as a tool that enables a hands-on learning experience of microcontroller study. The software used to develop this application are Unity3D and Vuforia. C# programming language has also been used to provide the command for the interaction between the interface and the application. After the development of the application was complete, it was tested by a group of electrical engineering students. Then, the students are required to fill out a survey on the system usability scale (SUS) test. The SUS score of this application is 62.5. It was found that the perceived usability of the evaluated AR application as a teaching tool for laboratory courses is acceptable. This response shows the marker-based AR application has the potential to be used as a teaching aid in engineering laboratory courses.

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1. INTRODUCTION

Augmented reality (AR) enables users to experience a blend of digital and physical realities, creating an immersive and interactive experience. AR applications use a camera, sensors, and software to identify and track real-world objects or locations, and then superimpose digital information onto them in real-time. This digital information can take the form of images, videos, 3D models, or text. AR technology can be used in a wide range of fields, including gaming, education, marketing, tourism, and healthcare. Some examples of AR applications include interactive product demos, educational simulations, and location-based experiences. AR has become increasingly popular in recent years, with the rise of mobile devices and wearable technology. As reported by the Malaysian Communications and Multimedia Commission (MCMC) in the handphone users survey 2021, smartphone use is highest among respondents under the age of 35, and 95.7% of smartphone users are students [1]. Many smartphones and tablets now have built-in AR capabilities, and there are also dedicated AR devices, such as smart glasses, that can provide a more immersive experience. The current smartphone camera is not only used for photo capturing but a video camera that is embedded in the smartphone has a sensor that can recognize and capture images to be used in AR applications [2].

In education, AR applications are used as a tool to convey knowledge and could improve students' performance [3]. Through AR technology, the traditional use of books and materials can be expanded beyond the information outside the classroom [4]. This approach makes the learning process more fun and interesting. Not only interesting, but the use of AR also allows a difficult subject to be better understood by students [5]. Apart from that, AR allows remote and distance learning to be realized and conducted [6]. It is also very surprising when AR can also help people with disabilities to learn and improve their skills [7].

Despite advancements in technology, the adoption of AR applications in engineering laboratories has not yet become widespread. Several reasons lead to this as discussed in [6], [8]–[10]. Some of the limitations in implementing AR in the teaching and learning process are i) High cost: AR equipment and software can be expensive, which can make it difficult for universities or laboratories with limited budgets to implement them on a large scale; ii) Technical challenges: AR technology requires a high level of technical expertise to develop, implement, and maintain, which may be a barrier for some educational institutions. Additionally, some AR applications may require a specific type of hardware or software, which can limit compatibility with existing laboratory equipment; iii) Lack of standardization: the lack of standardization in AR technology can make it difficult to develop widely applicable applications that work across different devices and platforms [11]; iv) Limited applications: while AR can enhance learning and student engagement, its use is limited to certain types of laboratory experiments. Some experiments may not benefit from AR applications or may require a level of complexity that is difficult to achieve with current technology; and v) Resistance to change: some educators and researchers may be resistant to change and may be hesitant to adopt new technology in their teaching practices, particularly if they are already familiar with traditional methods.

From the opposite perspective, in the laboratory session, students cannot self-configure lab equipment. All the experiments must be carried out under supervision. This is important to encounter emergencies or experience the impacts of misconfiguration that could cause equipment damage since practical exercises, are mostly based on specialized research equipment. Also, there is no way for students to practice and catch up outside of the lab schedule [12]. In some cases, the equipment to run the experiment is limited compared to the number of students who register for the course. As an alternative, to help students understand the course without restriction in terms of time, safety, limited equipment, and close supervision, AR technology could be an aid in the teaching and learning process including laboratory sessions. Standing teaching and face-to-face laboratory sessions could not be replaceable[13]. However, with the advantages of AR, it could assist laboratory courses. Advances in AR and technology become more accessible, it have the potential to transform engineering education by providing students with a more immersive and interactive learning experience [14]. Students could repeat the laboratory exercises to practice and understand the contents of the lab with minimal supervision or without any supervision. More than that, AR and virtual reality could minimize the exposition of students to harmful situations [15].

AR can be divided into marker-based and marker-less approaches that consist of location-based, superimposition, and projection-based. From the literature review done by Sirakaya and Sirakaya [16], a marker-based approach is preferred in most of the existing AR studies in the educational field. Marker-based works by triggering the marker by the camera and enhancing the visualization experience with the 3D object, video, animation, and explanation. The markers, frequently designed with distinctive patterns such as QR codes or other unique designs, serve as technological anchors. When an AR application recognizes a physical marker, digital content is superimposed on top of it. A project by Liccardo *et al*. [17] demonstrates how AR is used to replicate the laboratory session to help students and lecturers during pandemic restrictions. They build the object using the 3D technique and generate the marker for AR application using the Vuforia generator. Marker-based is also used by Alptekin and Temmen [18] to develop and strengthen practical abilities in working with electro-technical laboratory equipment and components. AR application design concept for a mobile device is prioritized in the study. To help engineering students understand the concepts of fluid dynamics mechanics, Sanderasagran *et al*. [19] designed an AR application to visualize the process and help the students solve the problems. The marker-based application was developed using Vuforia and Unity for Android devices. The development aims to provide an interactive application for education that can encourage engineering students to understand the complex flow and behavior patterns of fluid.

A work done by Benito *et al*. [20] shows the development of laboratory exercises based on AR software using a marker-less approach. The work has been developed and implemented for the computer engineering course. Next, Opris *et al*. [21] investigated the acceptance of AR applications in the field of power engineering, as it addresses the views of both students and teachers. The finding of their study shows that AR application is best used during laboratory sessions for students to relate the theoretical part and the practical session. Based on the survey conducted by Racha *et al*. [22], most of the students agree that emerging technology such as AR smart glasses could help their learning process. The study conducted by Han *et al*. [23] proposed an AR application that could be used to understand complex 3D information in mechanical assembly courses. The findings demonstrated that using AR considerably improved learning interest and academic achievements in the experimental group. Srivastava and Yammiyavar, [24] also proposed a work in progress on the development and usage of AR applications in the curriculum of engineering laboratories. The development of the application focuses on merging the internet of things (IoT) concepts with intelligence. Interesting work has been carried out by Moriello *et al*. [25] where an AR application is used to eliminate harmful radiation while conducting a physics experiment. The issue of enabling students to conduct experiments safely in the context of risky laboratory activities is addressed in the study. The previous research by Alvarez-Marin *et al*. [14] also shows the effectiveness of using AR applications in the teaching process. According to the survey conducted by the research, most of the respondents agreed that utilizing the app for the electrical circuits analysis study was convenient. The use of AR in promoting science and engineering studies is not only available for higher education but also has been carried out in elementary school. An example of the work shown by Moro *et al*. [26] is where the virtual laboratory prototype was developed using marker-based AR for teaching about planet Earth to children. Wirjadi *et al*. [27], created a boiling water experiment to demonstrate the impacts of heat capacity and to construct an interactive lab experiment for online learning to help the growth of AR in online chemistry education.

While AR has shown promise in educational settings, its adoption in engineering laboratories remains limited. Despite advancements in technology, several challenges hinder the widespread implementation of AR applications in engineering education. These challenges include high costs associated with AR equipment and software, technical complexities in development and implementation, lack of standardization, limited applicability to certain laboratory experiments, and resistance to change among educators. Moreover, in traditional laboratory sessions, students often face constraints such as limited access to equipment, restricted timeframes, and the need for constant supervision. These constraints highlight the importance of exploring alternative approaches to enhance the teaching and learning process in engineering laboratories.

To address these challenges, this study aims to develop and evaluate an AR application for exploring microcontroller study in engineering education. Microcontrollers play a crucial role in the development of embedded systems and are essential for engineering students in their project assignments. By leveraging AR technology, this application aims to provide students with an interactive and hands-on approach to understanding microcontroller concepts and capabilities. The contributions of this study lie in the development of an AR application tailored specifically for microcontroller study in engineering education. Unlike existing research, which primarily focuses on marker-based or marker-less approaches in laboratory settings, this study explores the integration of AR technology into microcontroller education, filling a gap in the literature. Additionally, the study seeks to evaluate the user experience of the AR application using standardized testing tools, such as the system usability scale (SUS), to provide empirical evidence of its effectiveness. The following sections of this manuscript will detail the methodology used to develop the AR application, present the findings of the user experience evaluation, and discuss the implications of the study for engineering education. Through this research, we aim to demonstrate the potential of AR technology to enhance learning experiences in engineering laboratories and contribute to the advancement of engineering education.

2. RESEARCH METHOD

2.1. Application development

The methodology part explains the flow of the project that takes place in succeeding the project. First and foremost, the storyboard was sketched to help direct the application's contents. Then, the type of software development kit (SDK) to make the AR application was identified. In this project, Vuforia and Unity3D software were used because both are powerful tools to create AR applications based on the widely used in industries such as gaming and education. The Vuforia engine provides a tool to create and manage markers for AR applications. To create a marker, the engine will define the size and shape of the target image or 3D model and assign it a unique ID. The markers will trigger AR experiences. The AR software recognizes the marker and overlays virtual content on top of it. The Vuforia engine uses advanced tracking and stabilization techniques to ensure that the virtual content remains aligned with the marker, even as the device and marker move around. This helps to create a seamless and immersive AR experience.

Meanwhile, Unity3D is a software used to develop virtual content for the AR application. This content can be 2D or 3D graphics, animations, or interactive elements. The content is aligned with the marker's position and orientation using Vuforia's AR camera. Unity offers strong capabilities for creating complex, intensely entertaining AR experiences that logically interact with the real environment and have the option to export apps to most major platforms [28]. For this project, we developed multiple scenes and a user interface (UI) button to display options for microcontroller types: Arduino Uno, Raspberry Pi Pico, and

ESP8266. These buttons facilitate navigation from the menu scene to the AR scene. To ensure the proper functionality of these buttons, a program in C# language was developed using a programming scripting tool. The general steps involved in developing the application include creating a database in Vuforia and adding a target image, generating a license key in Vuforia, downloading Unity Extension (legacy) as a Vuforia plug-in, integrating the plug-in into Unity (asset), designing the interface, programming using C# through Microsoft Visual Studio, running the project, setting up build settings in the Android platform and saving them in an apk file, and finally transferring the file to an android device and installing the app.

2.2. Perceived usability test

To evaluate the AR application, a group of students from engineering studies tested the application. Then, they need to answer the questionnaires that are surveyed via online Google form. The questionnaire consists of a SUS test that is used to measure the usability of the AR application to the user. According to Ibrahim *et al.* [29], a ten-item questionnaire with five-point Likert items ranging from 1 (strongly disagree) to 5 (strongly agree) is a reliable method for measuring the perceived usability of AR applications. The SUS test is a widely used tool for measuring the perceived usability of a system or product. It was developed in 1986 by Brooke [30] and has since become one of the most popular and reliable measures of usability.

The SUS test is a simple and quick survey consisting of 10 statements, each rated on a 5-point Likert scale ranging from strongly agree to strongly disagree. The 10 statements are designed to assess two key aspects of usability: the user's perception of the system's effectiveness (i.e., how well it helps them achieve their goals) and the user's perception of the system's efficiency (i.e., how easy it is to use). Table 1 shows the questionnaire included in the test. The participants were asked to answer the questionnaire right away after experiencing the AR application.

Table 1. A list of statements for the SUS test

No.	Question
1	I think that I would like to use this application frequently.
2	I found the application unnecessarily complex.
3	I thought the application was easy to use.
4	I think that I would need the support of a technical person to be able to use this application.
5	I found the various functions in this application were well integrated.
6	I thought there was too much inconsistency in this application.
7	I would imagine that most people would learn to use this application very quickly.
8	I found the application very awkward to use.
9	I felt very confident using the application.
10	I needed to learn a lot of things before I could get going with this application.

3. RESULTS AND DISCUSSION

3.1. AR application

The three microcontrollers used in this study are Arduino Uno, Raspberry Pi Pico, and ESP8266. The images serve as a marker, are detected by the camera on a mobile device, and are then used to activate computer-generated content which is 3D images and notes. The selected markers were made to follow them at any angle and from any distance. By rotating the marker, users can view the object from a different angle and in greater detail because it was made to be seen in 3D imagery. By doing so, a virtual illusion is created, which can increase user interest.

3.2. Perceived usability test analysis

There were only 28 participants involved in the user testing phase. A small sample size is suitable for the use of SUS as a usability measurement tool [30]. The 10 statements are designed to assess two key aspects of usability which are the user's perception of the system's effectiveness and the user's perception of the system's efficiency. The system’s effectiveness is presented by how well it helps the user to achieve their goals and the system’s efficiency is how easy it is to use. Figures 1-10 show the graphs of responses for the SUS test. Questions 1, 3, 5, 7, and 9 are the questions that are used to evaluate the effectiveness of the system shown in Figures 1, 3, 5, 7, and 9 where the color of the graph’s bar is blue. Then Figures 2, 4, 6, 8, and 10 show the graph analysis with a red bar for questions 2, 4, 6, 8, and 10. The graphs are the distribution of feedback that covers the system’s efficiency.

Regarding effectiveness, the study reveals that users generally found the AR application to be useful and effective. For instance, most respondents agreed or strongly agreed that they would like to use the application frequently as responded in question 1. Similarly, the majority found the application easy to use in question 3, felt confident while using it in question 9, and agreed that the application functions were well-integrated in question 5. Additionally, respondents believed that people would quickly learn to use the application as shown in question 7. These responses suggest that the AR application effectively met the needs of users, offering a positive user experience. However, it's important to note that these responses represent a sample of users, and further testing is necessary to determine the overall effectiveness of the application.

On the other hand, the study also examines the efficiency of the AR application. Responses to questions such as "I found the application unnecessarily complex" in question 2 and "I thought there was too much inconsistency in this application" in question 6 suggest that some users found the application to be overly complex and inconsistent. However, responses to questions like "I think that I would need the support of a technical person to be able to use this application" in question 4 and "I needed to learn a lot of things before I could get going with this application" in question 10 indicate that users generally did not require technical support and did not perceive a significant learning curve. Moreover, an even distribution of responses for question 8 which is "I found the application very awkward to use" suggests that users' perceptions of the application's efficiency vary.

In conclusion, while the AR application demonstrated effectiveness in meeting users' needs and providing a positive user experience, its efficiency is more nuanced. While some users found it complex and inconsistent, others did not require technical support and accepted it as a teaching aid. However, further analysis and feedback from users are necessary to draw a more definitive conclusion on the efficiency of the AR application and to improve its usability. The perceived usability score of this application is 62.5. It was found that the perceived usability of the evaluated AR application as a teaching tool for laboratory courses is acceptable. From the analysis of the result, the perception of the user toward the effectiveness of the AR application is good compared to the efficiency of the system. Several factors can contribute to a user's perception of a system's efficiency such as ease of use, speed, reliability, and integration.

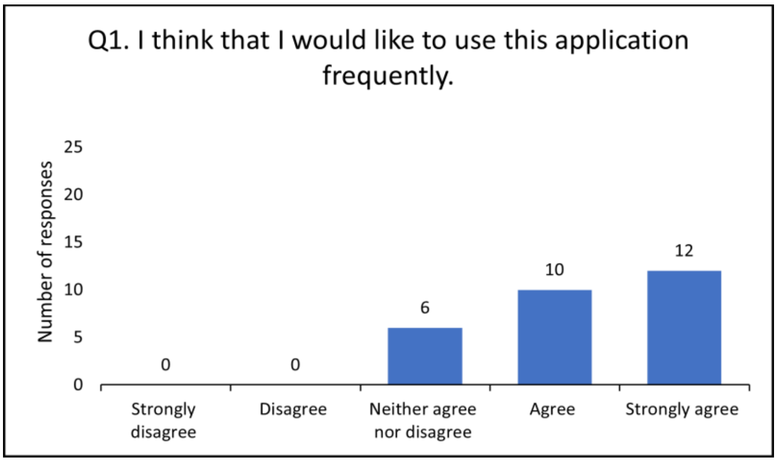

Figure 1. The graphs of responses for the SUS test in response to statement No. 1

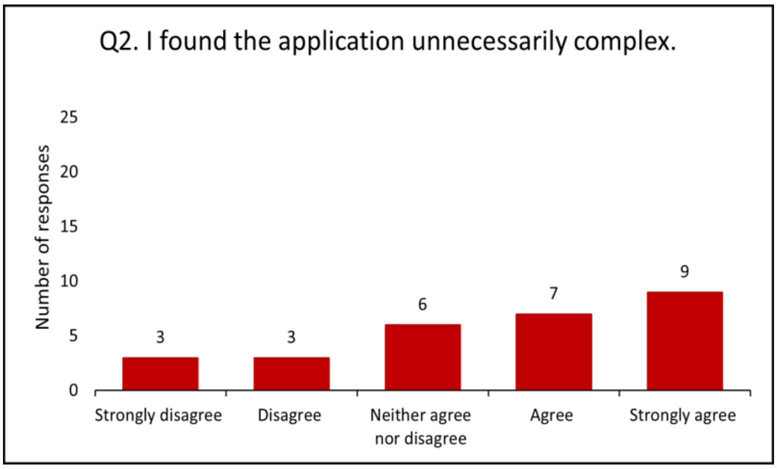

Figure 2. The graphs of responses for the SUS test in response to statement No. 2

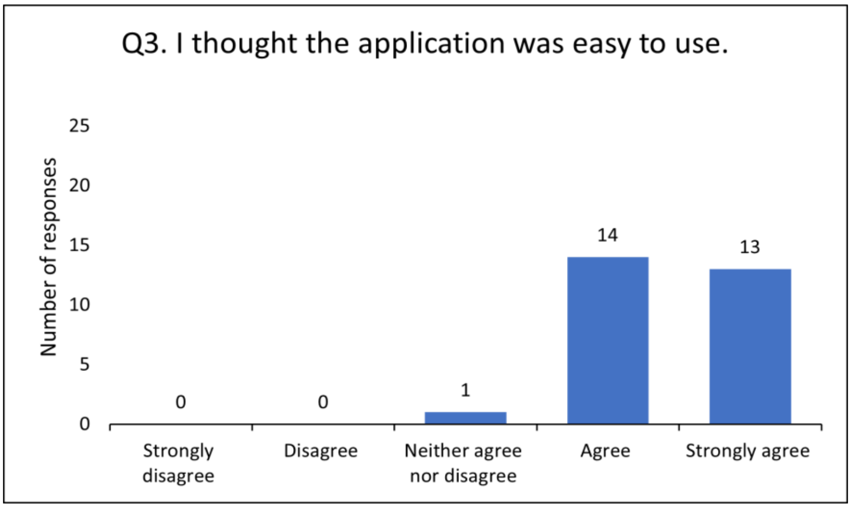

Figure 3. The graphs of responses for the SUS test in response to statement No. 3

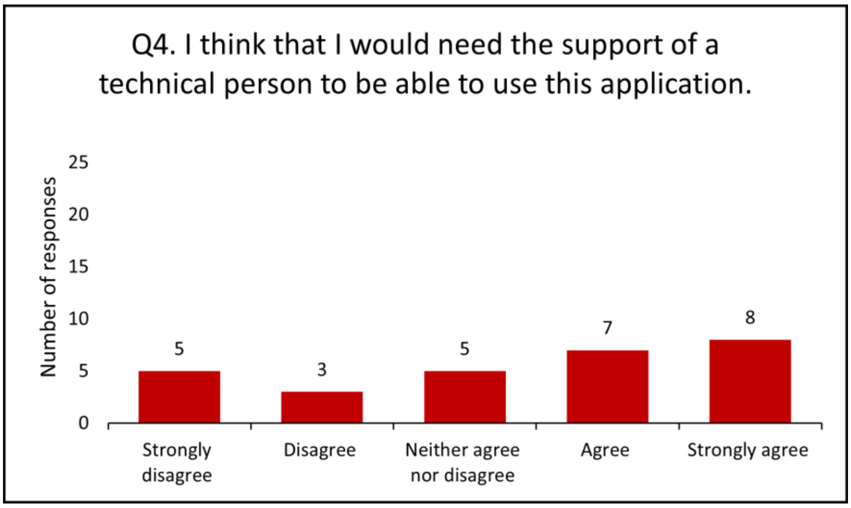

Figure 4. The graphs of responses for the SUS test in response to statement No. 4

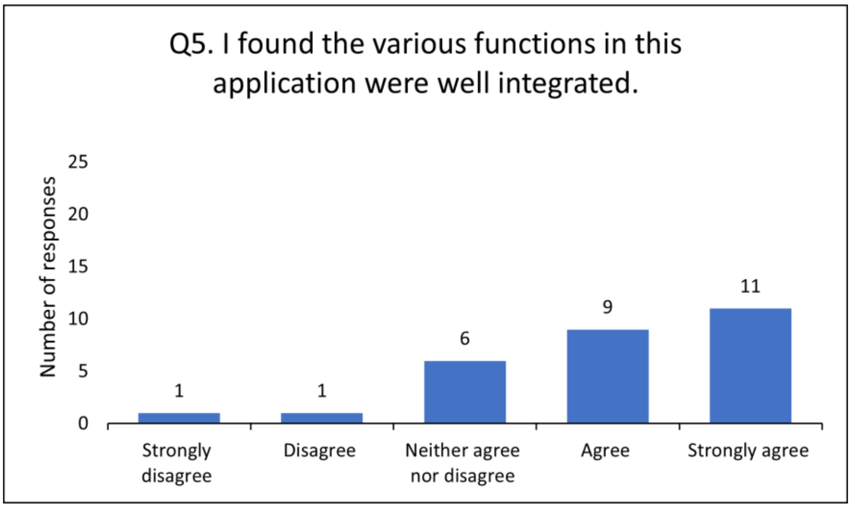

Figure 5. The graphs of responses for the SUS test in response to statement No. 5

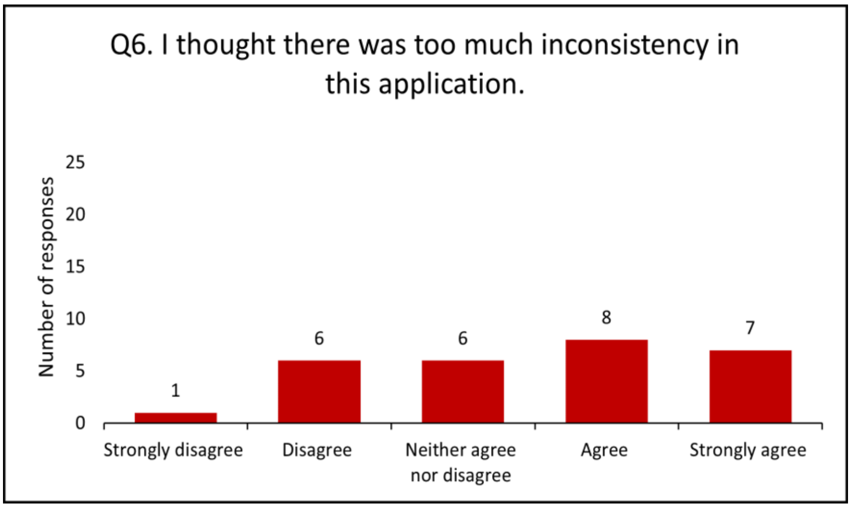

Figure 6. The graphs of responses for the SUS test in response to statement No. 6

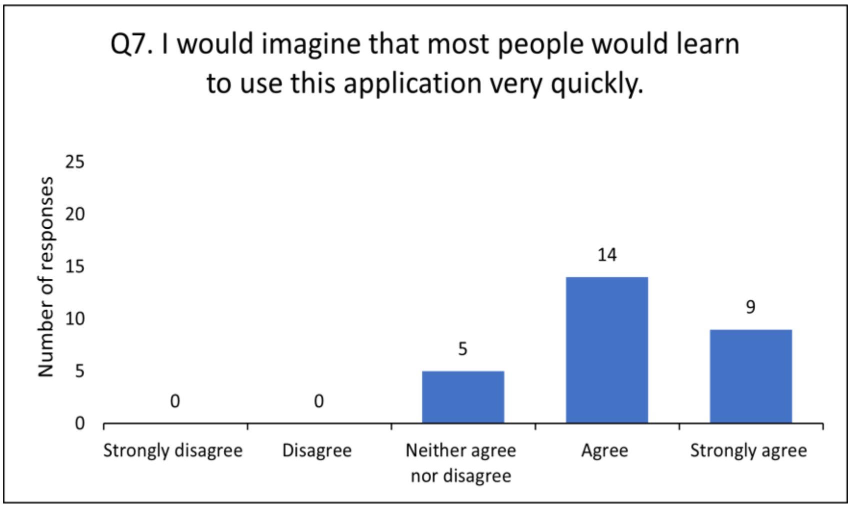

Figure 7. The graphs of responses for the SUS test in response to statement No. 7

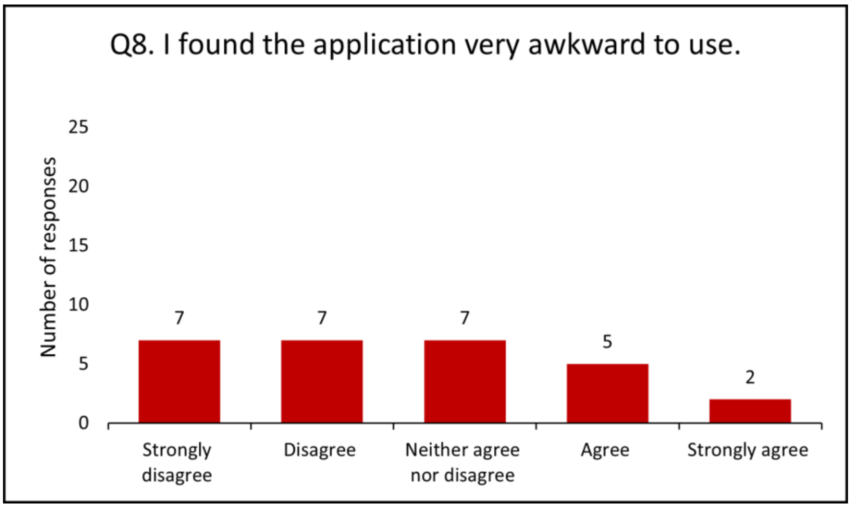

Figure 8. The graphs of responses for the SUS test in response to statement No. 8

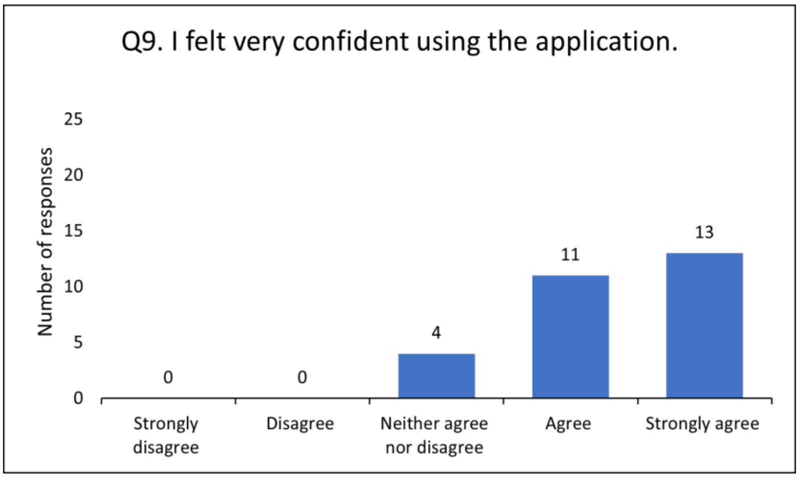

Figure 9. The graphs of responses for the SUS test in response to statement No. 9

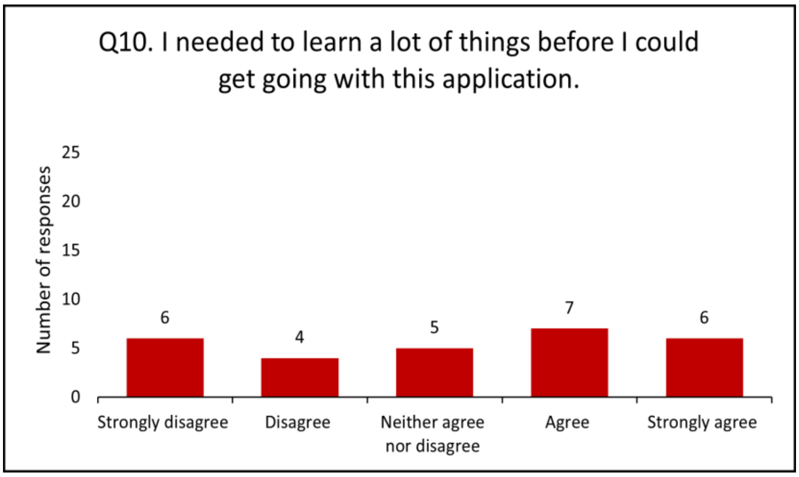

Figure 10. The graphs of responses for the SUS test in response to statement No. 10

4. CONCLUSION

This study highlights the effectiveness of AR applications in engineering labs. We implemented a virtual lab using marker-based AR, showing AR's potential to enhance learning. Despite challenges like limited functionality and user experience issues, AR applications proved valuable in delivering course content. We offer recommendations for improving application design, usability, and functionality. User experience is crucial, requiring easy navigation and integration with other devices. Optimizing performance and scalability is important, along with incorporating AI to personalize learning. AR apps should support multiple platforms for wider accessibility and continuous updates based on feedback are necessary. AR benefits students, educators, and technology providers by bridging theoretical knowledge and practical application. Collaborative efforts are crucial for exploring AR's potential in engineering education and driving innovation in educational practices. In conclusion, AR applications offer immersive and personalized learning experiences, revolutionizing engineering education for the next generation.

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