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ADVANCING MECHANICAL DESIGN PEDAGOGY WITH HOLOLENS 2 MIXED REALITY ENVIRONMENTS: A CYBERGOGY EXPLORATION

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Abstract: Mixed Reality (MR) and Augmented Reality (AR) technologies have gained popularity among companies due to their ability to engage user with digitalized 3D media and information. The ability to interact with the virtual objects while keeping the real-world scenery make them very useful in certain fields. Nowadays, traditional teaching methods, which involve using paper to deliver information and exercises, are outdated. With the advancement of technology, the modernization of teaching process should be utilized to improve the quality of education, especially involving laboratory experiment. Current learning process can be improved in many aspects as traditional method is time-consuming and prone to errors, which affect the result. The goal of this work is to develop an MR application for Programmable Logic Controller (PLC) experiments, evaluate the effectiveness of the developed MR application for the chosen laboratory experiments and implement MR in education system to achieve goal 4 (Quality Education) of Sustainable Development Goal (SDG). Microsoft Hololens 2 and a smartphone were used in this experiment together with a Programmable Logic Controller (PLC) Lab Apparatus. AR and MR application were developed, beginning with modeling 3D in SOLIDWORKS, then transferred to Blender 3.4, Unity 3D, and Vuforia engine. The scripts were then compiled, and the scenes were rendered before the file can be exported into the smart glasses. Thirty (30) participants from Department of Mechanical and Manufacturing Engineering were introduced to MR and AR technologies. This case study collected three main data during the experiment: Task Completion Time (TCT), error counts and number of hints. Participants were also required to answer a set of questionnaires at the end of the experiment. The result showed that 60% of the participants preferred to use MR-based instruction compared to other methods. MR-based instruction also receives good and positive feedback from the questionnaires.

Key words: Mixed Reality (MR), Augmented Reality (AR), Programmable Logic Controller (PLC), Sustainable Development Goal (SDG).

1. INTRODUCTION

Mixed Reality (MR) technology, which integrates the features of Virtual Reality (VR) and Augmented Reality (AR), is increasingly being researched and developed for various applications. MR offers enhanced visual and auditory experiences, allowing users to interact with digital objects within a real-world environment. This dual capability has captured the interest of companies aiming to develop advanced MR devices for use in fields such as education, healthcare, manufacturing, and design. The COVID-19 pandemic significantly disrupted traditional educational methods, particularly affecting laboratory learning experiences. Despite the shift to online learning and the use of cybergogy methods (Figure 1), many students faced challenges like adapting to new environments, time management issues, and lack of motivation.

Traditional learning methods in the Department of Mechanical and Manufacturing Engineering at the Universiti Putra Malaysia remain prevalent, relying on lectures, video briefings, printed manuals, and tutor explanations. These methods often lead to difficulties in understanding laboratory procedures, longer completion times, and increased errors. Although VR has been utilized, many students report its lack of realism and inadequate content instruction. To address these issues, this project aims to develop an MR application for Programmable Logic Controller (PLC) [2] experiments, enhancing the current teaching methods through cybergogy learning (Figure 2). The project evaluates the effectiveness of the MR application in improving laboratory experiment outcomes and its potential contribution to achieving quality education under the Sustainable Development Goals (SDGs).

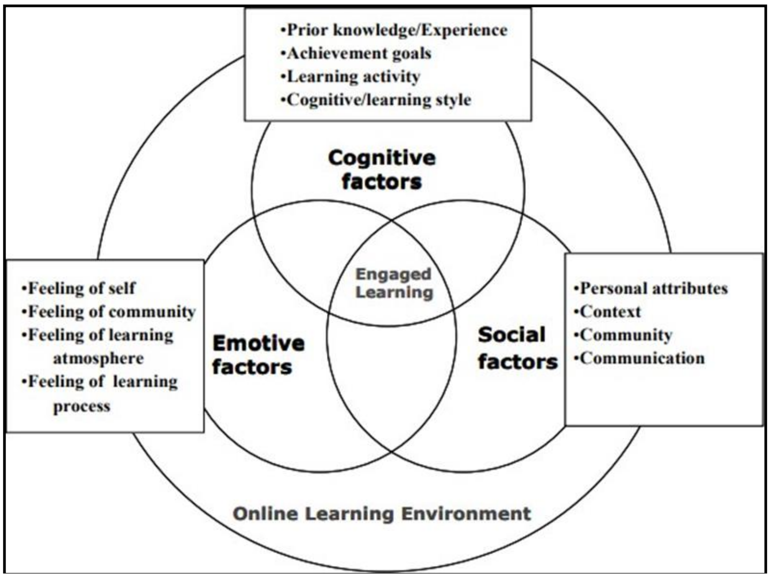


Fig. 1. The model of Cybergogy for engaged learning, [1]

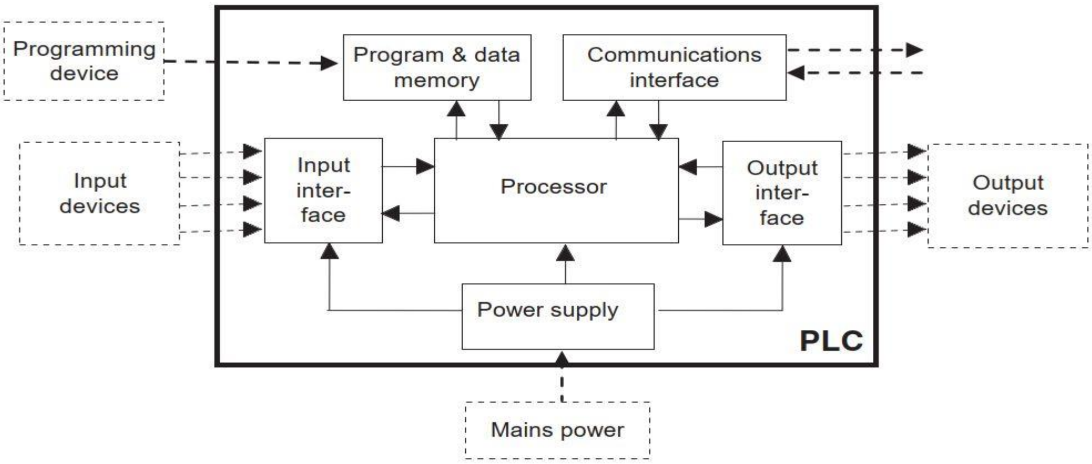


Fig. 2. The system of Programmable Logic Controller, [2]

The project involved development of a marker-based AR application, a paper-based reference, and a fully developed MR application using Microsoft HoloLens 2. Twenty volunteers from the Universiti Putra Malaysia participated in the PLC laboratory experiments. The effectiveness of the MR application was assessed by comparing task completion times, error counts, the number of hints used, and feedback on the learning experience. This study aims to demonstrate significant improvements in the quality of education through the application of MR technology in laboratory settings.

2. AUGMENTED REALITY AND MIXED REALITY APPLICATION

The influences of the Industry 4.0 Revolution (IR 4.0) on human capital development and consumer behavior have been identified by [3] which are shifting the work environment and the drivers for human capital development and consumer behavior. [3] stated that augmented reality (AR) currently plays an important role in undertaking the challenges in integrating technologies to expedite the march towards Industrial Revolution 4.0. Mixed reality (MR) environments contain a combination of real and virtual world information. MR can be utilized to visualize information, remote collaboration, human-machine interface, design tools as well as education and training. [4] introduced the reality-virtuality continuum that defines mixed reality and identified a series of variations of technologically modified forms of reality that correspond to today's augmented and virtual reality technologies as Figure 3.

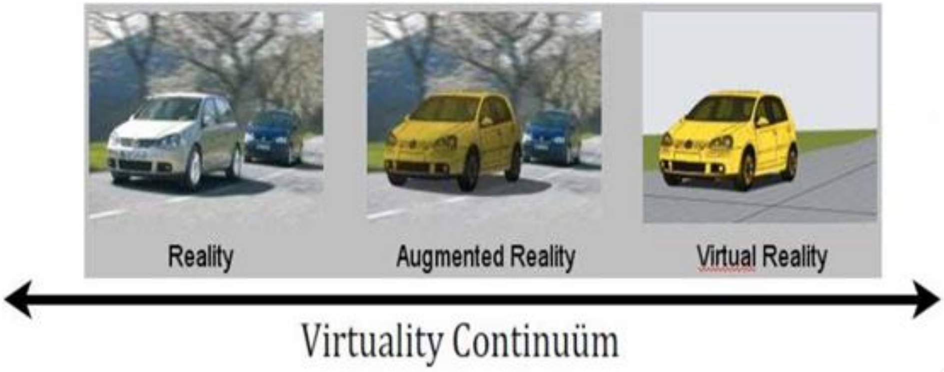


Fig. 3. A virtuality continuum, [4]

3. PEDAGOGY AND CYBERGOGY

Cybergogy, merging concepts from pedagogy and anthropology, is a modern cyber-learning paradigm emphasizing self-centered and interactive learning in virtual environments [5]. Pedagogy involves teaching methods, curriculum design, instructional strategies, and assessments to aid student development. Cybergogy, often using problem-based learning, leverages modern technologies like Augmented Reality (AR) to simplify educators' tasks and provide diverse learning materials to students. The goal is to enhance educational effectiveness and accessibility.
The cybergogy model integrates cognitive, emotional, and social aspects of online learning. Its practical application in education aims to improve these factors, thus enhancing student performance. Cybergogy's flexibility is especially beneficial for adults who prefer online learning [6]. Additionally, cybergogy can be grounded in Social Constructivist epistemology, where learners build knowledge through interactions, supported by social engagement [7]. This approach employs Learning Archetypes in 3D environments to achieve desired learning outcomes. Incorporating technologies like Mixed Reality, AR, and Virtual Reality is essential for creating effective cybergogy environments. Figure 4 shows model of Cybergogy underpinned by Social Constructivist epistemology [7].

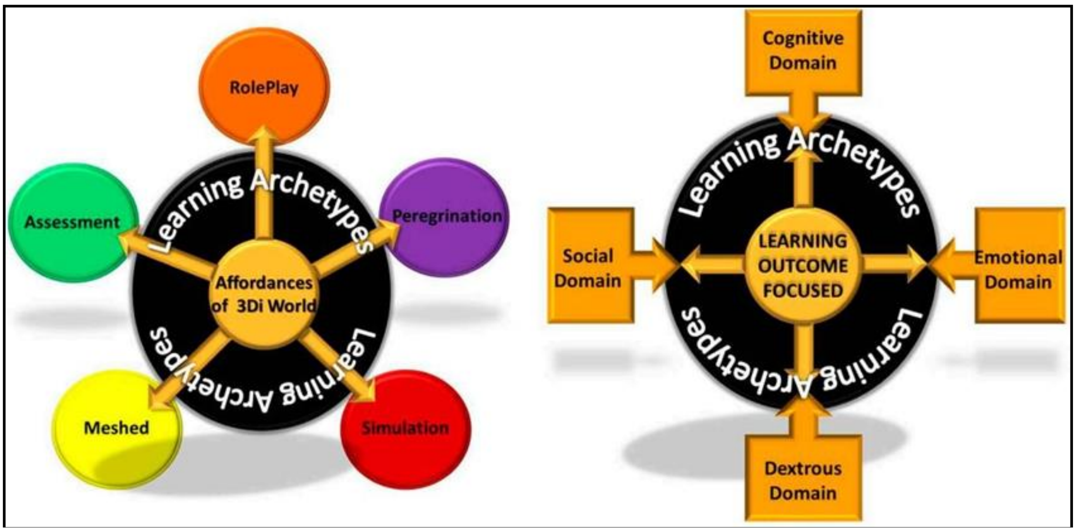
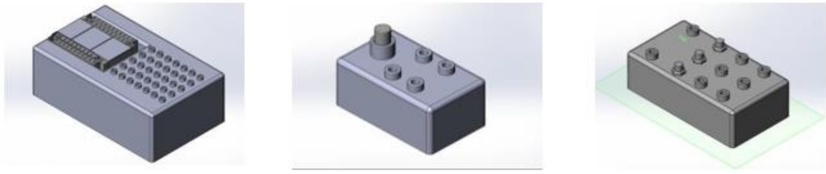


Fig. 4. The model of Cybergogy underpinned by Social Constructivist epistemology [7]

4. MATERIALS AND METHODS

The development of the applications used several software which are Solid Work for 3D model to develop the Programmable Logic Controller (PLC) components as Figure 5a, then animated to fbx extension using Blender 3.4. software as Figure 5b.



(a) (b) (c)

Fig. 5a. The 3D models of the Programmable Logic Controller (PLC) that consist of (a) PLC Box Unit, (b) Push Button and (c) LED Buzzer Output

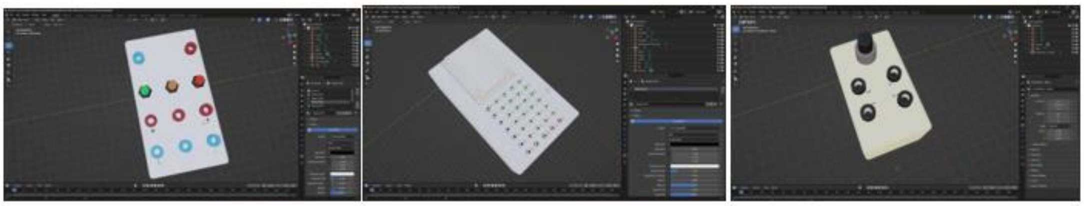


Fig. 5b. The Programmable Logic Controller (PLC) components animated to fbx format

Once the 3D model is completed, a cross-platform game engine by Unity 3D was being used to develop the AR and MR application as Figure 6. Then, a Vuforia engine software was being used to transform the model to kit (SDK) and UI Toolkit were installed beforehand.

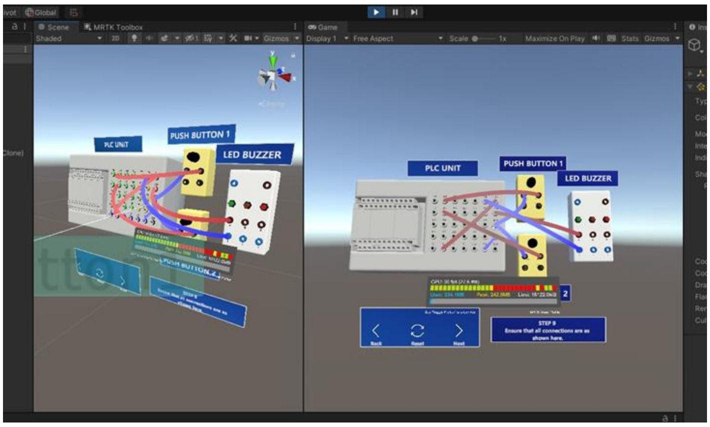


Fig. 6. The arrangement of the models and wires inside Unity 3D for Mixed Reality (MR) application

4.1 Build Application for AR and MR display

Due to its capable hardware and versatile features, the Xiaomi Black Shark 4 is an excellent platform for augmented reality (AR) experiences. Compared to the MR application, the hardware used is Microsoft Hololens 2 which is a Head Mounted Device (HMD) that specializes in mixed-reality applications. Figure 7a shows the on-screen tablet display in the AR application. Figure 7b shows the Microsoft Hololens 2 application display. Some of the User Interface (UI) objects were used to manage users' actions and provide instructions for the user. Scripts have been compiled and the scenes were rendered before the file could be exported into the smart glasses. The finished application was then tested by participants to prove the effectiveness of the application.

4.2 Experimental procedure

These tests, which include MR-based, AR-based, and paper-based techniques, requires thirty (30) participants in total. These participants were divided evenly into three groups: Group A, Group B, and Group C. Group A began the experiment with the MR-based method, Group B with the AR-based method, and Group C with the paper-based method. Before beginning the experiment, participants were explained the experiment workflow. The participants were expected to complete the studies by following the instructions provided. During the experiment, each participant's Task Completion Time (TCT), error counts, and number of tips were recorded. After the experiment was completed, a survey questionnaire was distributed to all participants to evaluate the overall performance and effectiveness of the developed application. Figure 8 shows the flowchart of the experiment.

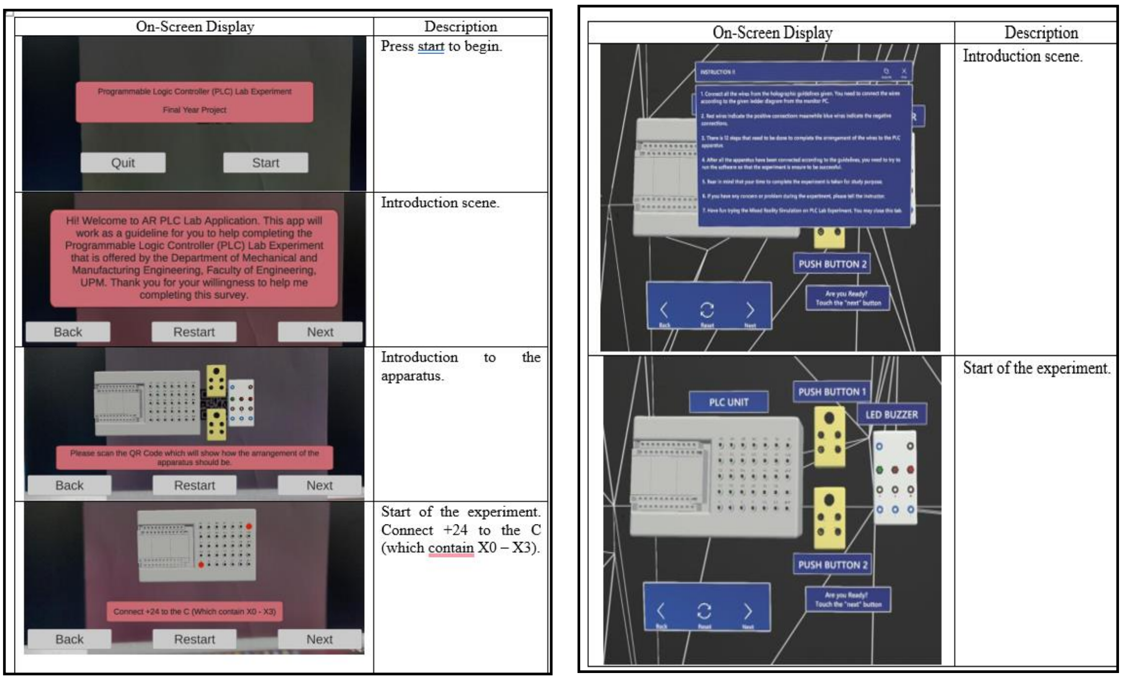


Fig. 7. (a) AR application display in TAB screen and (b) Mixed reality in Hololens-2 display

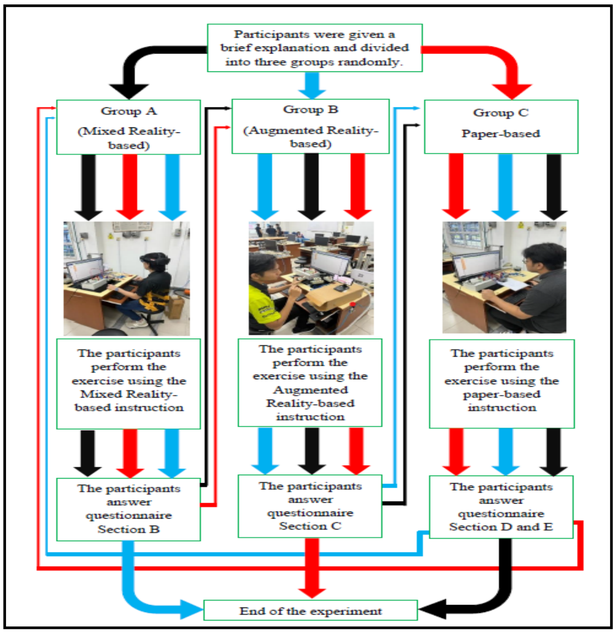


Fig. 8. Workflow of the experiment

5. RESULTS AND DISCUSSION

The participants consist of 30 students, 24 men and 6 women from the Department of Mechanical and Manufacturing Engineering ranging from 21 to 27 years old. The mean and standard deviation of age is 23 and 1.2865 respectively. Based on the Task Completion Time as Table 1, number of errors and number of hints. The data obtained was used to analyze and find potential significant differences between these three instructions.

Table 1. Data of Task Completion Time (TCT)

Groups	Mean	Variance	Standard Deviation
Mixed Reality-based instruction	6.9293	0.7523	0.8674
Augmented Reality-based instruction	5.9330	1.1777	1.0852
Paper-based instruction	8.7423	3.8258	1.9560

A percentage of Improvement (POI) for mixed reality-based and augmented reality-based compared with paper-based instruction are calculated using the formula (1) and (2).

$$\text{Percentage of Improvement for AR} = \frac{\text{Score for AR Based Instruction} - \text{Score for Paper Based Instruction}}{\text{Score for Paper Based Instruction}} \times 100\% \quad (1)$$

$$\text{Percentage of Improvement for MR} = \frac{\text{Score for MR Based Instruction} - \text{Score for Paper Based Instruction}}{\text{Score for Paper Based Instruction}} \times 100\% \quad (2)$$

The data of the Percentage of Improvements (POI) for both MR and AR are represented in Table 2.

Table 2. The data of Percentage of Improvements (POI)

Data	Mixed Reality-based Instruction (%)	Augmented Reality-based Instruction (%)
Task Completion Time (TCT)	20.74	32.13
No. of Errors	79.59	87.76
No. of Hints	89.20	87.77

Based on the Percentage of Improvement (POI), the TCT of employing Mixed Reality-based instruction and Augmented Reality-based instruction improved by 20.74% and 32.13%, respectively. These results suggest that TCT is shorter when using these instructions over paper-based instructions. The POI for mistake counts employing Mixed Reality-based instruction and Augmented Reality-based instruction is 79.59% and 87.76%, respectively. There is a significant improvement in reducing errors when experimenting compared to paper-based education. Finally, the POI for the number of clues when employing Mixed Reality-based instruction and Reality-based instruction is 89.20% and 87.77%, respectively. This suggests that there has been a significant improvement in minimizing the number of hints asked by participants to encourage them to solve the problem themselves. This also demonstrates that incorporating Cybergogy learning into laboratory investigations using Mixed Reality-based instruction and Augmented Reality-based instruction resulted in a positive response from participants. Thus, it is possible to conclude that Mixed Reality-based instruction and Augmented Reality-based instruction can be a reliable way to conduct laboratory experiments in engineering education while also promoting Cybergogy learning.

Survey Analysis was conducted to the participants after the experiment on their feedback about the developed application. The survey consists of four part which are parts A, B, C, and Section E. The part contains demographic questions, Mixed Reality-based instruction, Augmented Reality-based instruction, paper-based instruction, and overall feedback. Part A consists of three questions about the device interaction when using the applications. Part B also consists of three questions on their learning experience when using the three mediums. Part C contains three questions that asked about the feedback using the three mediums. Lastly, Section E consists of three questions which explained the preference method of the participants. The mean rating for the survey from the MR-based group, AR-based group and paper-based group are tabulated as in Table 3.

Based on the poll results, participants agree that Mixed Reality is more effective than other methods. Even though the mean scores for Mixed Reality and Augmented Reality instruction is the same, they are greater than paper-based instruction. These technology-based instructions can enhance participants' confidence, allowing the experiment to be completed with minimal supervision from others.

They also agreed that these strategies should be used in the educational system in such a way that they benefit both students and instructors. However, according to a preference poll, most participants feel that Mixed Reality-based training is more favorable than Augmented Reality-based instruction and Augmented Reality-based instruction.

Table 3. The mean of each question for the MR-based, AR-based, and paper-based groups.

Survey	**Device Interaction**			**Learning Method**			**Overall**		
	Part A			**Part B**			**Part C**		
Group	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
MR	4.4667	4.6667	4.5000	4.6000	4.4667	4.6667	4.3667	4.3333	4.5667
AR	4.5667	4.6000	4.3000	4.5333	4.5667	4.4667	4.6000	4.3333	4.6333
Paper	2.1000	2.1667	2.3000	2.1000	1.9000	1.8667	2.2667	2.2667	2.0000

Augmented Reality-based training is preferred over other techniques due to its clear instruction and data presentation, as well as its ability to adapt to varied learning styles and contexts. In the most recent survey, most participants agreed that Mixed Reality-based instruction and Augmented Reality-based instruction help to achieve Sustainable Development Goal (4) - Quality Education because of their advanced technology, which can help students experience new learning styles while also improving cybergogy-based learning. Thus, these findings demonstrate that the use of Cybergogy with the use of current advanced technology can be more beneficial than the old traditional way.

6. CONCLUSIONS

The study concluded with the development of two innovative applications: a Mixed Reality (MR) application for PLC laboratory experiments using Microsoft HoloLens 2, and an Augmented Reality (AR) application for PLC laboratory experiments using a smartphone. The effectiveness of these MR and AR applications in the context of Cybergogy learning was thoroughly evaluated. The findings indicated that both MR and AR applications significantly outperformed traditional paper-based instruction. Additionally, participant feedback, gathered through questionnaires, revealed high satisfaction with the developed applications, with mean response scores surpassing those for paper-based methods. Notably, Mixed Reality-based instruction emerged as the preferred method for PLC laboratory experiments within the Cybergogy framework. Furthermore, most participants concurred that integrating MR and AR in the education system substantially contributes to achieving Goal 4 (Quality Education) of the Sustainable Development Goals (SDG). The use of Mixed Reality (MR) can help to achieve Sustainable Development Goal (SDG) 4 – Quality Education which ensures that all students have access to high and excellent quality knowledge, inclusive education, and new learning experiences. The Sustainable Development Goal (SDG) can be achieved through overcoming the challenges, exploring the possibilities, and conducting research on the implementation of Information and Communication Technology (ICT) in education, with a specific focus on maximizing its potential in the classroom.

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