Applied Computer Science, vol. 20, no. 1, pp. 17–27
doi: 10.35784/acs-2024-02

Submitted: 2024-01-07 | Revised: 2024-02-28 | Accepted: 2024-03-07

Keywords: AR-based circuit practice, AR education, AR practice, practice evaluation

*Hae Chan NA* [0009-0002-5027-2832]*, *Yoon Sang KIM* [0000-0002-0416-7938]**

# A STUDY ON AN AR-BASED CIRCUIT PRACTICE

**Abstract**

*Recently, the number of AR-based practice cases has been increasing. In this paper, the effect of AR-based circuit practice was examined through an experiment with 60 subjects (control group: 30, experimental group: 30). The report score, completion time, question count, and USE questionnaire were used in the analysis. As a result of the experiment, the report score was significantly increased by 15.48% in the experimental group (△report: +18 points) than in the control group (△report: +7 points). Question count decreased twice as much in the experimental group (△question: -18 times) as in the control group (△question: -9 times). The completion time of the experimental group (△time: -16 min) was reduced by approximately 4 min more than that of the control group (△time: -12 min), however, the difference was not statistically significant. The USE questionnaire received evaluations of 6.0 or higher (on a 7-point scale) in all categories (usefulness, ease of use, ease of learning, satisfaction). Therefore, From the experimental results, the proposed AR-based circuit practice is confirmed to be more effective than traditional circuit practice.*

## 1. INTRODUCTION

Circuit education is a compulsory course for most engineering majors at the lower undergraduate levels. The circuit education is taught through theory and practice to learn the basic concepts of electricity and electrons, and to apply them in circuit wiring (Park, 1998; Oh et al., 2020). In circuit education, most trainees are new to circuits. Therefore, trainees have difficulties in practice due to various factors, such as inexperience in using the equipment, wiring the circuit, and using the element.

As the metaverse market expands, augmented reality (AR) technology, which combines virtual objects (or information) with real-world images, is also increasingly being applied in the fields of education and manufacturing.

ZSpace Inc. offers AR solutions that enable learners to understand engineering and scientific concepts through interactive experience, while TeamViewer's frontline offers an industrial AR platform designed to enhance productivity for workers in the manufacturing sector (Zspace, 2023; Teamviewer, 2023). Scope AR's worklink utilizes AR technology to

* Korea University of Technology and Education, Department of Computer Science and Engineering, BioComputing Lab, Republic of Korea, skgocks5729@gmail.com
** Korea University of Technology and Education, Department of Computer Science and Engineering, Institute for Bioengineering Application Technology, BioComputing Lab, Republic of Korea, yoonsang@koreatech.ac.kr

provide training and remote assistance for workers in manufacturing and maintenance sectors (ScopeAR, 2023).

Particularly, this AR technology is highly effective in engineering practice, which mainly deals with problems and simulations that are difficult to understand intuitively (Yusuf et al., 2023; Cao & Yu, 2023; Diegmann et al., 2015; Takrouri et al., 2022). To overcome the above-mentioned difficulties, various studies have attempted to use AR for circuit practice.

Avilés-Cruz and Villegas-Cortez (2019) proposed a system that augments the information of logic gates, and the usability evaluation confirmed the high satisfaction and usefulness from the trainees. Álvarez-Marín et al. (2021) proposed a system that augments the current and voltage values of the element, and from the experimental results, it was confirmed that the proposed system increases the convenience for the trainees. Reyes-Aviles and Aviles-Cruz (2018) proposed a system that augments current and voltage values on real elements through measuring equipment, and the usability evaluation confirmed that the interest and willingness of trainees increased.

However, most studies have qualitatively evaluated the proposed systems; thus, there are insufficient studies that quantitatively compare their effectiveness with traditional practice (without AR). This paper deals with whether circuit practice using AR is more effective than traditional circuit practice. The proposed AR circuit practice is an extension of our previous research (a method that uses AR for PLC practice), applying AR to real breadboard-based circuit practice (Lee & Kim, 2011). The educational effectiveness of the proposed method was examined, both quantitatively and qualitatively.

## 2. PROPOSED AR-BASED CIRCUIT PRACTICE

This section describes the proposed AR-based circuit practice method. The proposed method is an extension of previous research to utilize AR in general circuit practice (Lee & Kim, 2011). It consists of three functions: 1) augmented guide, 2) wiring decision, and 3) feedback. An overall flowchart of the proposed method is shown in Fig. 1.

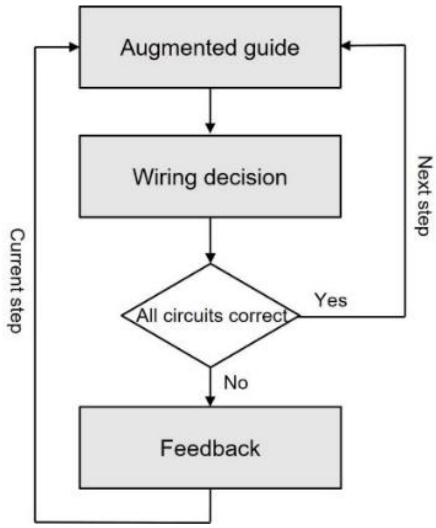
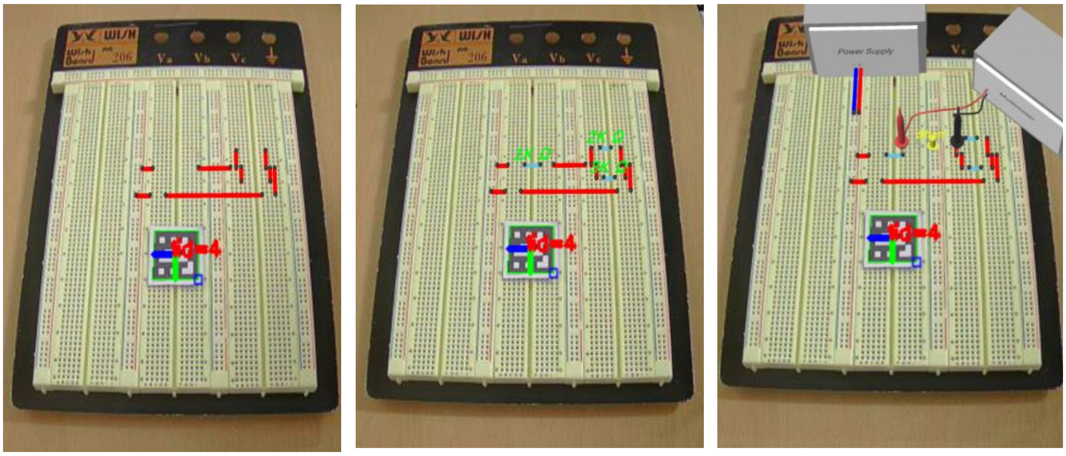



**Fig. 1. Flowchart of an AR-based circuit practice**

### 2.1. Augmented guide

The augmented guide is a function that augments the 3D virtual wiring guide (hereafter augmented circuit) and guides the trainee to wire the circuit as given in practice while looking at the augmented circuit. The coordinates of the three-dimensional virtual space and the physical breadboard are registered on the tracked marker. The function provides wiring practice in three steps, as shown in Fig. 2: 1) cable wiring, 2) element wiring, and 3) equipment wiring.




(a) (b) (c)

**Fig. 2. Implemented augmented guide: (a) cable wiring; (b) element wiring; (c) equipment wiring**

The cable wiring step guides the positions where cables should be connected to the breadboard using 3D model-based cables, as shown in Fig. 2(a). Through this step, trainees can easily wire the circuit.

The element wiring step guides the positions for placing elements, such as resistors, along the wired cable using 3D models (elements and texts), as shown in Fig. 2(b). With this guide, trainees can easily verify the element wiring positions and usage of elements (e.g., pin connections and polarity directions).

The equipment wiring step guides the positions for connecting power and measurement equipment (power supply and multimeter) using 3D models (cables and equipment), as shown in Fig. 2(c). This allows trainees to easily verify the cable connection positions and measurement methods corresponding to the equipment.

### 2.2. Wiring decision

The wiring decision checks whether the trainee has wired the circuit to match the augmented circuit (described in 2.1). The function compares the circuit wired by trainee (hereafter wired circuit) with augmented circuit through three steps, as shown in Fig. 3: 1) wiring recognition, 2) preprocessing, and 3) coordinate comparison.

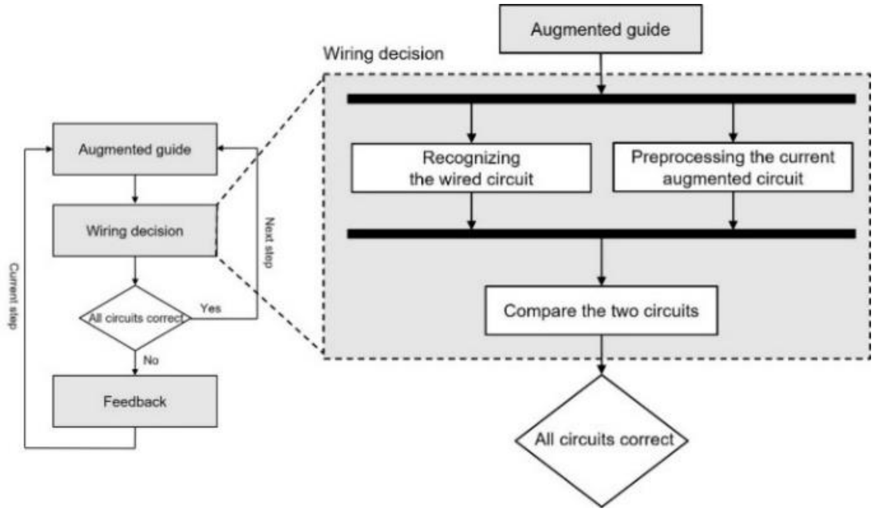



**Fig. 3. The procedure for wiring decision**

The wiring recognition step recognizes the wired circuit in the captured image through the trainee's smartphone. The recognition of cables and elements is processed based on RGB colors. The process of recognizing the wired circuit within the breadboard and the target for the recognition are shown in Fig. 4.

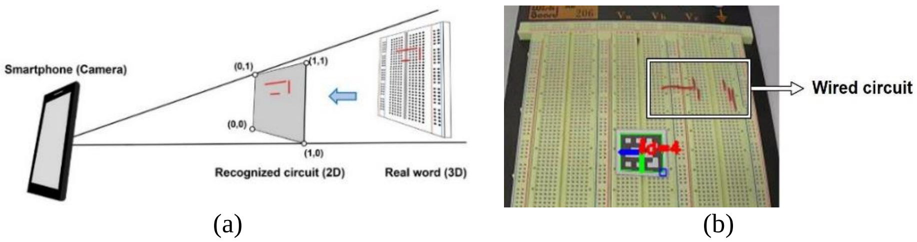



**Fig. 4. A step of circuit recognition: (a) wired circuit projected into $\mathbb{R}^2$ (RGB-based recognition); (b) recognition target example**

The preprocessing step preprocesses the augmented circuit for comparison with the wired circuit. This step projects the augmented circuit into two dimensions equal to the resolution of the captured image. The process of preprocessing the augmented circuit and the target for the preprocessing are shown in Fig. 5.

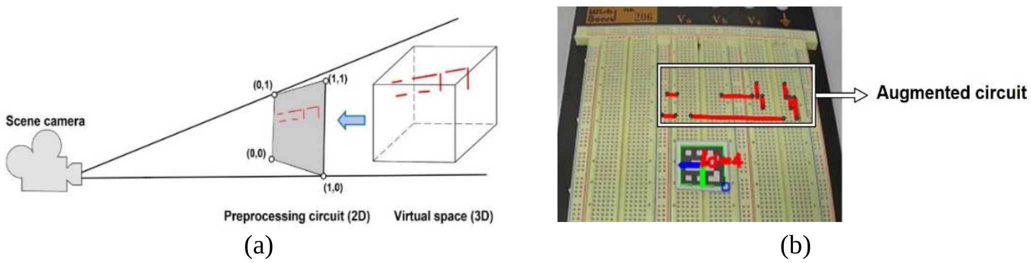



**Fig. 5. A step of preprocessing: (a) augmented circuit projected into $\mathbb{R}^2$; (b) preprocessing target example**

The coordinate comparison step compares the two circuits converted to two-dimensional data (the recognized wired circuit and the preprocessed augmented circuit) by pixel-by-pixel. If the wired circuit is identical to the augmented circuit, the next step of the augmented guide proceeds; otherwise, the feedback function proceeds. The process of comparing the two circuits and the targets for comparison are shown in Fig. 6.

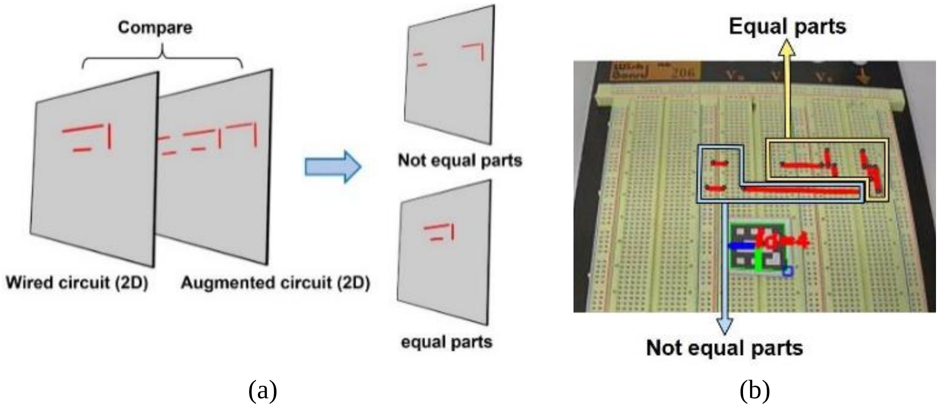



**Fig. 6. A step of coordinate comparison: (a) coordinate comparison of two circuits; (b) comparison targets example**

## 2.3. Feedback

The feedback (message and color) is provided to the trainee based on the wiring decision. If there are errors in the wired circuit, the function identifies error positions (that are different from the augmented circuit) and indicate the errors via the color of the augmented circuit (False: red, True: blue) with a message about rewiring. Fig. 7 shows the procedure and an implemented example of the feedback function.

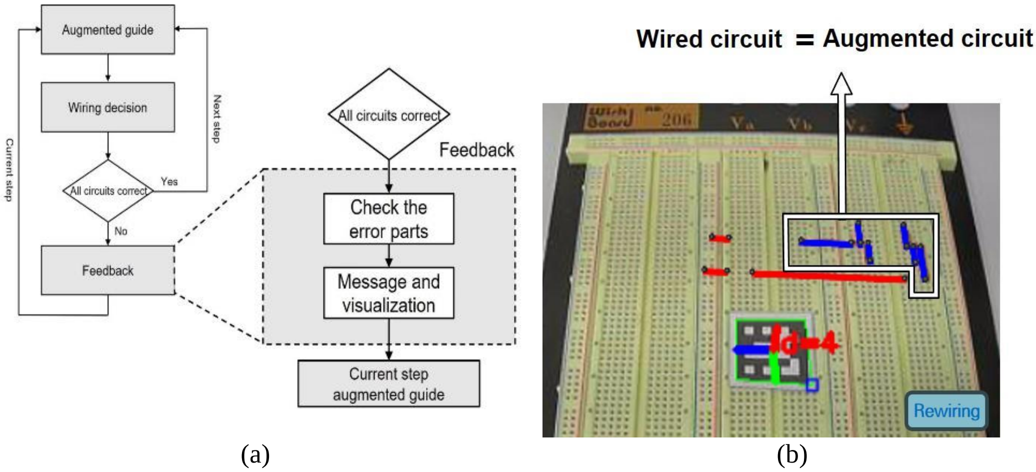
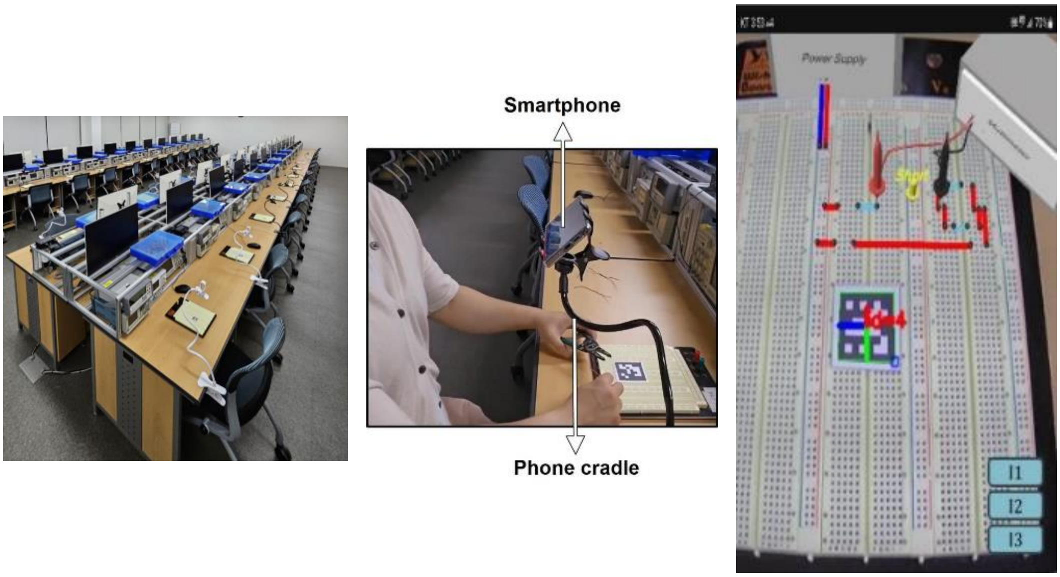



**Fig. 7. The procedure for feedback and an implemented example: (a) the procedure for feedback; (b) implemented example**

## 3. EXPERIMENT AND RESULTS

### 3.1. Experimental environment

In this section, the effectiveness of proposed AR-based circuit practice is examined through a lab session included in the engineering curriculum. The experiment was performed with a total of 60 first-year computer science students (control group: 30, experimental group: 30), and the experiment was conducted twice (total 2 hour/times) at one-week intervals (to minimize group differences in competence using change measures). In the first week of the experiment (hereafter 1st experiment), both experimental and control groups performed traditional circuit practice. In the second week of the experiment (hereafter 2nd experiment), the experimental group performed the proposed AR-based circuit practice, while the control group performed the same traditional circuit practice as in the 1st experiment. The experimental environment is shown in Fig. 8. The individualized practice environment with AR consists of a smartphone cradle, smartphone, and AR circuit practice application, as shown in Fig. 8(b). The AR circuit practice application was developed with Unity and distributed to trainees.




(a) (b) (c)

**Fig. 8. Experimental environment: (a) overall experimental environment; (b) an individual experimental setup using the proposed method; (c) AR application example**

The experiment followed the procedure shown in Fig. 9.

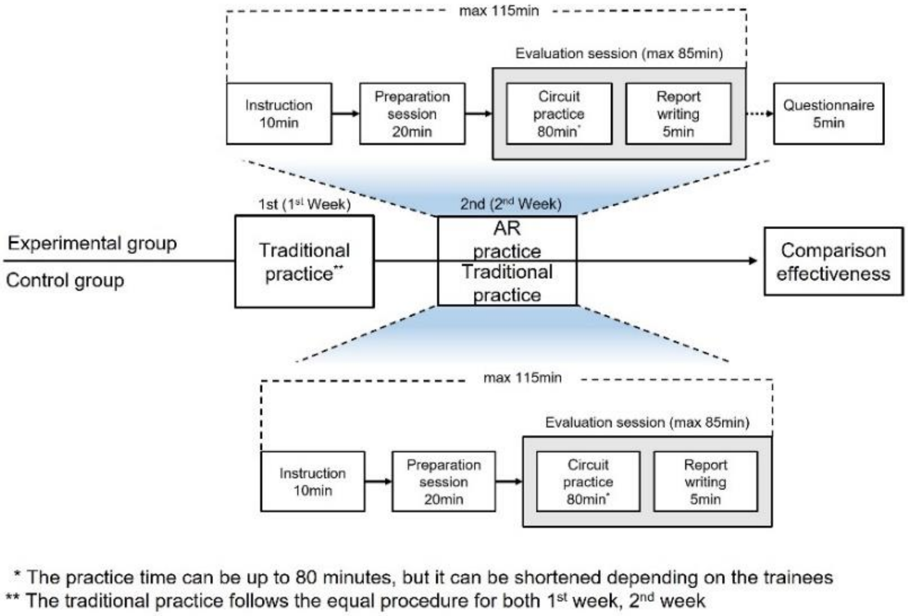



**Fig. 9. Experimental procedure**

## 3.2. Results

The quantitative evaluation used the report score, completion time, and question count. The report score is obtained by the trainee's construction of the given circuit through practice and by comparing the measured values (e.g., current and voltage) to theoretical values. The completion time is the time taken by the trainee to finish the given practice. In this experiment, the completion time was defined as starting from the moment all trainees were ready for the practice and ending when the measurements stated in the provided report were fully recorded. The question count is the number of questions that trainees asked the instructor during the practice (questions were limited to those related to wiring and equipment usage (e.g., power supply, multimeter)). For qualitative evaluation, the USE questionnaire, the representative usability questionnaire, was used (Lund, 2001).

Quantitative evaluation was measured in both the experimental and control groups, whereas qualitative evaluation was only measured in the experimental group. As both groups satisfied normality according to the Central Limit Theorem, a parametric test was used for the analysis (outliers were removed) (Kwak & Kim, 2017).

1. Quantitative evaluation

Bartlett's test was conducted to confirm whether the variances of the report scores were equal between the two groups (control group, experimental group). As a result, the homogeneity of variances was not satisfied. Therefore, a Welch's t-test was used in the analysis to compare the mean changes in report scores of the two groups. It was confirmed that the experimental group (1st mean: 77.40, 2nd mean: 95.83) showed significant increase in their score by 15.48% than that of the control group (1st mean: 86.67, 2nd mean: 93.89) ($p=0.02$). This means that AR-based practice can teach and guide trainees on how to wire circuits and to use equipment more effectively than the traditional practice.

To confirm whether the variances of the completion times were equal, a Bartlett's test was conducted. As a result, the homogeneity of the variance was satisfied. Therefore, an independent two sample t-test was used to compare the mean changes in average completion time of the two groups. It was confirmed that the experimental group (1st mean: 45 min, 2nd mean: 29 min) took longer on average for each experiment than the control group (1st mean: 35 min, 2nd mean: 22 min) (due to differences in group capabilities). However, the reduction in average practice time was approximately 4 minutes greater for the experimental group. Despite this improvement, the results were not statistically significant ($p=0.14$). The lack of significant differences between the two groups appears to be attributable to the fact that both experiments were at a basic circuit practice level.

As a result of the experiment, the question count was biased toward a few trainees, resulting in no difference in the average of each group; thus, it was difficult to confide in the statistical significance of the means and standard deviations. We compared the question count between the two groups using sum comparisons instead of averages. In the control group, the question count decreased from 15 in the 1st experiment to 6 in the 2nd experiment. The question count in the experimental group decreased from 24 in the 1st experiment to 6 in the 2nd experiment. It confirmed that the experimental group had a two-fold decrease in the question count compared with the control group. This shows that AR-based circuit practice is effective in addressing trainees' questions. The results of the quantitative evaluation are shown in Tab. 1.

**Tab. 1. Quantitative results**

| **Metrics** | | **Experiment** | | **delta** | **p-Value** |
|---|---|---|---|---|---|
| | | **1st** | **2nd** | | |
| Average report score | Conventional | 86.67 | 93.89 | 7.22 (+) | 0.02 |
| | Proposed | 77.40 | 95.83 | 18.43 (+) | |
| Average completion time (seconds) | Conventional | 2108 | 1372 | 736 (-) | 0.14 |
| | Proposed | 2733 | 1760 | 973 (-) | |
| Total question count | Conventional | 15 | 6 | 9 (-) | - |
| | Proposed | 24 | 6 | 18 (-) | |

A report is a record of the data (current/voltage) measured by the trainees.
The completion time is the duration it took for the learner to wire the circuit and measure all the presented data.
The total question count is the sum of the inquiries from trainees about circuit wiring and equipment usage to the instructor.

2. Qualitative evaluation

In the results of the USE questionnaire (on a 7-point scale) of AR-based circuit practice, the usefulness was rated at 6.1, the ease of use and satisfaction were both rated at 6.0. In addition, ease of learning received the highest score of 6.3. The percentage results for each category are shown in Fig. 10.

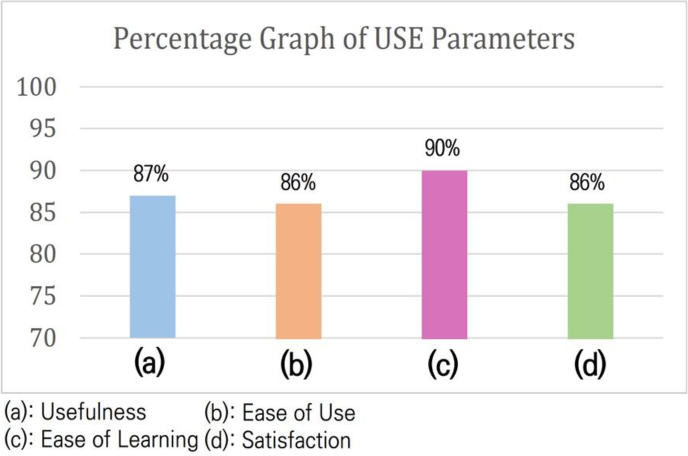



**Fig. 10. A percentage of usability parameters results**

Additionally, the usability level of AR-based circuit practice was confirmed through Equation (1). From the usability score of 87% (percentage of eligibility), it was confirmed that the utilization of AR in circuit practice was highly effective for trainees (Arifin & Maharani, 2021; Prihantono et al., 2020; Widoyoko, 2012) (as shown in Tab. 2).

$$Percentage\ of\ Eligibility\ (\%) = \frac{Observed\ score}{Expected\ score} \times 100\% \tag{1}$$

**Tab. 2. Classification of eligibility categories**

| Score in percent | Categories |
|---|---|
| <21 | Very Unworthy |
| 21-40 | Not Worthy |
| 41-60 | Enough |
| 61-80 | Worthy |
| 81-100 | Very Worthy |
| * Percentage of eligibility of the proposed method is 87% | |

## 4. CONCLUSION

In this paper, a method of applying AR to general circuit practice was proposed by extending our previous research, which applied AR to PLC wiring. The proposed method provides an augmented guide to the circuit to be wired on a real breadboard and provides feedback by determining whether the trainee wired the actual circuit according to the augmented circuit. An experiment was conducted with 60 students (experimental group: 30, control group: 30) to compare the effectiveness of the proposed method with traditional circuit practice (without AR). The evaluation used both quantitative assessment (report score, completion time, question count) and qualitative assessment (USE questionnaire).

As a result of the experiment, the report score was significantly increased by 15.48% in the experimental group (△avg score: +18.43) than in the control group (△avg score: +7.22) ($p=0.02$). The completion time was 4 min less for the experimental group (△avg time: -16 min 13s) than for the control group (△avg time: -12 min 15s), but this was not statistically significant. The question count was reduced two-fold in the experimental group (△total question: -18) compared to that in the control group (△total question: -9). For the USE questionnaire, usefulness was evaluated at 6.1, ease of use and satisfaction at 6.0, and ease of learning at 6.3 (on a 7-point scale). The usability level of the qualitative evaluation scores was calculated, and it was confirmed that AR-based circuit practice was very useful (percentage of eligibility (%) = 87).

From these experimental results, we confirmed that AR-based circuit practice was more effective than traditional practice. This paper examined the effectiveness of basic circuit practice. As such, this paper makes the following important contributions. First, it demonstrates that AR technology can play an important role in improving learning outcomes, particularly in helping trainees understand complex concepts and practice. Second, it shows that the application of AR technology can improve comprehension in the learning process, such as reducing the number of questions. This means that it can create an environment where trainees can learn more independently. Finally, it suggests that it can improve workers' task understanding, productivity, and work efficiency in the real-world manufacturing sector.

In the future, we plan to examine whether the proposed method is still effective when extended to intermediate or advanced circuit practice.

## REFERENCES


Álvarez-Marín, A., Velázquez-Iturbide, J. Á., & Campos-Villarroel, R. (2021). Interactive AR app for real-time analysis of resistive circuits. *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*, *16*(2), 187-193. https://doi.org/10.1109/RITA.2021.3089917

Arifin, S., & Maharani, L. (2021). Assessing user experience of a mobile application using usability questionnaire method. *Applied Information System and Management*, *4*(1), 1-10. https://doi.org/10.15408/aism.v4i1.20265

Avilés-Cruz, C., & Villegas-Cortez, J. (2019). A smartphone-based augmented reality system for university students for learning digital electronics. *Computer Applications in Engineering Education*, *27*(3), 615-630. https://doi.org/10.1002/cae.22102

Cao, W., & Yu, Z. (2023). The impact of augmented reality on student attitudes, motivation, and learning achievements-a meta-analysis (2016–2023). *Humanities and Social Sciences Communications, 10,* 352. https://doi.org/10.1057/s41599-023-01852-2

Diegmann, P., Schmidt-Kraepelin, M., Eynden, S., & Basten, D. (2015). Benefits of augmented reality in educational environments-a systematic literature review. *Wirtschaftsinformatik Proceedings 2015, 103,* https://aisel.aisnet.org/wi2015/103

Kwak, S. G., & Kim, J. H. (2017). Central limit theorem: the cornerstone of modern statistics. *Korean journal of anesthesiology*, *70*(2), 144-156. https://doi.org/10.4097/kjae.2017.70.2.144

Lee, J. O., & Kim, Y. S. (2011). An AR-based wiring practice for PLC training. *Journal of International Council on Electrical Engineering*, *1*(4), 425-429. https://doi.org/10.5370/JICEE.2011.1.4.425

Lund, A. M. (2001). Measuring usability with the use questionnaire. *Usability interface*, *8*(2), 3-6.

Oh, D., Shim, S., & Choi, H. (2020). Development of augmented reality based electronic circuit education system. *KIPS Transactions on Computer and Communication Systems*, *9*(12), 333–338. https://doi.org/10.3745/KTCCS.2020.9.12.333

Park, J. S. (1998). Electrical engineering education through the undergraduate system. *The Korean Institute of Electrical Engineers*, *47*(2), 46-48.

Prihantono, M. R., Usman, T., & Wakid, M. (2020). The development of learning media's "tutorial video for setting the front wheel alignment with a 3D spooring tools" at SMK N 1 magelang. *Journal of Physics: Conference Series*, *1700*, 012061. https://doi.org/10.1088/1742-6596/1700/1/012061

Reyes-Aviles, F., & Aviles-Cruz, C. (2018). Handheld augmented reality system for resistive electric circuits understanding for undergraduate students. *Computer Applications in Engineering Education*, *26*(3), 602-616. https://doi.org/10.1002/cae.21912

ScopeAR. (2023). *Worklink*. https://www.scopear.com/

Takrouri, K., Causton, E., & Simpson, B. (2022). AR technologies in engineering education: Applications, potential, and limitations. *Digital*, *2*(2), 171-190. https://doi.org/10.3390/digital2020011

Teamviewer. (2023). *Ubimax*. https://www.teamviewer.com/en/ubimax/

Widoyoko, E. P. (2012). *Teknik penyusunan instrumen penelitian*. Yogyakarta: Pustaka Pelajar.

Yusuf, Y. A. M., Ismail, I., Hamzah, W. M. A. F. W., Amin, M. A. M., & Arsad, M. A. M. (2023). A literature review on mobile augmented reality in education. In B. Alareeni & A. Hamdan (Eds.), *Innovation of Businesses, and Digitalization during Covid-19 Pandemic* (Vol. 488, pp. 875–888). Springer International Publishing. https://doi.org/10.1007/978-3-031-08090-6_56

ZSpace. (2024). https://zspace.com/