Augmented Reality (AR) Technology-Based Learning: The Effect on Physics Learning during the COVID-19 Pandemic

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***Abstract*—The COVID-19 pandemic has significantly disrupted education and has instantaneously shifted education from being conducted predominately 'face to face' to being totally 'online'. For most teachers, this unexpected teaching approach has impelled them into finding ways to provide the same quality of education to their students. One way of doing this is by adopting educational technologies in learning and teaching, including the use of augmented reality (AR) technology. AR technology has been integrated into the field of physics education. In this study, the effects of AR technology on understanding of the concepts of electricity in an online learning environment for 11th-grade students was investigated. Pretest and posttest were carried out in the control group and the experimental group. The results showed that AR technology improved understanding of electrical concepts for the students in the experimental group compared to the control group, with a very significant difference between both groups. This research contributes to the development of AR technology in education, especially in relation to the teaching and learning of abstract physics concepts.**

***Index Terms*—Augmented reality, conceptual understanding, COVID-19, online learning, physics.**

I. Introduction

The spread of the COVID-19 pandemic has significantly affected the whole world in various aspects of life including education and social interaction. In most countries, including Indonesia, the government has issued an educational directive for teaching and learning to be conducted online to reduce the risk of the pandemic [1]. Teachers and students are forced to adopt online learning to ensure the continuity of learning despite the pandemic. In this context, the integration of technology plays an important role in online learning because of the increase in technology usage [2]. Technology that is easy to use is necessary to provide concrete solutions for online learning and to enable incorporation of virtual contents. Through such an approach, learning and teaching may go on as usual despite the constraints resulting from the pandemic situation.

One option of virtual software for learning is Augmented Reality (AR). An augmented reality (AR) is an advanced system that combines real virtuality in three-dimensional (3D) technology [3]. This technology, compared to other advanced learning technologies, is easy to use. The reason is that this technology increases reliability, can be easily used and can also involve various senses and make learning of physics, which is abstract and difficult, easier [4]. In addition, one of the sensible checks for abstract knowledge is computer simulations or renewable technologies because a technological approach would allow greater control over the nature of the events that students observe and thus provide an explicit awareness of new relationships between sudden and slight emerging concepts [5]. Moreover, AR is also considered a technology that fills the gap between reality and the virtual world [6], [7]. Augmented reality has been transformed into a platform that enables students to observe phenomena that might not be encountered in real life and it can also be tailored to suit students' level of understanding [8]. Therefore, AR has been shown to increase students' understanding and attitude in learning of physics [9]. Besides, AR allows visualisation of abstract concepts by providing opportunities for students to learn new knowledge that has never been learned to avoid conceptual errors [7], [10]. This indicates that AR has a powerful role in the field of education, with the potential to revolutionise learning as its components will be able to provide opportunities for exploration of learning that is difficult to apply, especially with regard to the basic concepts of the material [11].

In fact, in learning about electricity, the learning problem that often occurs among students is misconceptions since the lack of visualisation causes students to experience misconceptions in understanding concepts of electricity [12]-[16]. In the reviewed studies, it was discovered that students often have misunderstanding about electrical concepts [17]-[21] and found it hard to distinguish between voltage and battery [18], [22], [23]. Previous studies indicated that students found it most difficult to understand concepts in topics related to electricity, including the concept of an electric circuit [21], [24], electric current, potential difference, and resistance in a current flow [25], [26]. Based on the problems identified in extant studies, it is not easy to address learning of physics concepts using only online learning without any alternative to support students so that they would learn better.

In such cases, the literature shows that AR has already been applied in learning and teaching in schools. In particular, AR helps students to develop new knowledge and increase students' analysis in physics. Thus, AR is more effective than that of the conventional media used by teachers [27]. Students can interact actively with the content virtually [28].

Manuscript received April 20, 2021; revised July 19, 2021.
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doi: 10.18178/ijiet.2022.12.2.1596

Studies revealed that AR could have a positive effect on students' teaching and learning process [29]-[31], motivation to study [10], [32], and on students' involvement in solving problems [29], [33]-[35]. As mentioned earlier, AR contributes by promoting student learning and by supporting the online teaching environment during the COVID-19 pandemic. In addition, problems that students' encounter in learning physics such as in learning about electricity and understanding the related concepts can be better addressed through AR since it can help improve the information collected through the different senses [36], [37]. During this pandemic situation, having the AR platform installed in the smartphone would enable visualisation of abstract concepts to be carried out in detail using AR. Thus, AR is flexible in its usage, easy to operate, and can support online learning.

The goal of AR depends on how the systems are integrated for teaching and learning from the education perspective. Several studies mentioned that AR could intensify integration of technology-based learning [38], innovation [39], and collaboration [40], [41]. Learning using AR has also been said to create a positive environment among students [42]-[44].

However, only a few studies have investigated how AR affect the understanding of physics in online learning and teaching during the COVID-19 pandemic. Thus, this raises the question of how online learning and teaching can benefit from the use of AR and subsequently increase the level of understanding in learning physics among students. The use of AR could help to increase students' understanding and augment learning even though the teaching and learning are conducted online because of the COVID-19 pandemic. Therefore, this work investigated students' understanding of physics concepts through the use of an AR application for learning, focusing on the differences of the level of understanding between the experimental and control groups of 11^{th}-grade senior high school students before and after using AR during the COVID-19 pandemic.

II. Methodology

A. Research Design

In the present study, the quasi-experimental design was applied to investigate the effects of AR on students' understanding of physics concepts related to the topic of electricity, especially in overcoming students' misconceptions. This research design used the intact classes available [34], [45]. The students were then placed in the control and experimental groups based on their pretest results. Pretest results showed the average value of the control group was (M = 53.79, SD = 8.974) while for experimental group, it was (M = 58.58, SD = 7.796). Both groups had studied electricity previously, which is the rationale for choosing these classes.

However, students in one of the groups, namely the experimental group, used AR application to assist their learning in the class. Then, the students' level of understanding after learning about electricity was evaluated via posttest towards the end of the learning sessions. This method helped to measure the effects of AR in developing students' understanding in learning Physics between the two groups.

B. Sample

The study sample involved 60 students, consisting of 11^{th}-grade science students in high school whose age ranged from 15 to 16 years old. The sample was selected by considering the fact that the students had never used any AR application before. The sample was chosen using the purposive sampling method since this study only involved 11^{th}-grade senior high school students studying physics subject. The schools were also selected based on their willingness to participate in the AR survey by considering telecommunication facilities. Two schools participated in this study, while one class of science from School A was selected as the group control and another class from School B was the experimental group.

Before the implementation of the study and the collection of data in the schools, the authors had sought permission and obtained approval to conduct the research at the schools from the Ministry of Education and the respective school principals. At the same time, the teachers, and students were informed about the purpose of this study. The schools, teachers, and students involved in this study were also assured of anonymity and confidentiality.

C. Teaching and Learning Design Based-AR Application

The topic of electricity related to dynamic and static electricity was the focus of this study because the topic is challenging for students. The AR application has a great potential to provide students a clear and deeper conceptual understanding of the theoretical and abstract concepts in the topic compared to traditional learning because the latter tend to focus on basic procedures and fails to develop critical thinking or knowledge construction in students [46]. Furthermore, due to the current pandemic situation, it is not possible for teachers to conduct lab classes and face-to-face classes. For this reason, the use of AR will provide students with an alternative learning experience, particularly during online classes. Thus, carrying out teaching and learning innovations using AR application is necessary as it could help to describe the concepts clearly to students, particularly since students would not be able to attend physical classes and would be relying on online learning. The concepts related to electricity are already difficult to grasp when learning face-to-face and they are even more so when students are learning online during the pandemic situation. Many students find it challenging to understand the concept of electricity as they have difficulty accessing learning materials and understanding explanations from the teachers during online classes.

The teaching and learning activities in the AR application were designed and developed by the authors based on the textbooks and worksheet guidance for physics education sourced from the Ministry of Education of the Republic of Indonesia. The guidebooks and worksheets have been validated by the respective Ministry of Education. Three learning theories, namely constructivism, constructionism, and self-determination were used as the basic theories that guided the development of the AR application.

The constructivist theory underlay the development of AR in this study. The theory was chosen so that students are encouraged to construct ideas that are scientifically correct which would later bring about meaningful understanding in the students, including overcoming the misconceptions. Constructivist learning clearly differs from ordinary learning practices where the passive reception and transmission of information usually occurs from one individual to another [47]. In contrast, constructivism focuses on assisting students in moving from a preliminary understanding to a complete and real comprehension.

Meanwhile, the constructionist theory allows students to interact with the learning objects in a virtual environment. In this study, constructionist theory was utilised to foster new ideas and active participation of students using external simulations, which would encourage the students to be directly involved in problem solving and in providing feedback to help rectify misconceptions. The AR application was used to develop the students' basic skills in learning of physics problems by giving students assignments and simulation to enhance their critical thinking skills [48]. In summary, the constructivist pedagogy selected that focused on students' active learning is relevant to the goal of the AR application which was to make the learning sessions more active in the process of overcoming students' misunderstandings [49]. AR applications can serve a variety of purposes in learning, but one of the most essentials is that they allow students to engage with real-world contexts in a virtual mode. Thus, AR was utilised in this study to develop interactive learning sessions that would expose the students to new situations and experiences, allowing them to experiment with diverse approaches and ways of thinking. The students would benefit from the application of the constructivist and constructionist theories as these theories would enable the students to better understand and visualize the abstract physics concepts through the hands-on and minds- on activities in the AR application.

Additionally, the self-determination theory is relevant in the AR development because this theory encourages students' independent learning. The self-determination theory (SDT) was also employed in this study to ensure that the AR application continue to drive the students' innate desire for self-learning and personal development. Furthermore, the theory encourages students to find explanations and solutions to their learning challenges, particularly to overcome misconceptions. In other words, the self-determination theory was mainly used in this study to encourage the students to overcome their misunderstandings of the concepts rather than focusing on their motivation to learn. However, this theory would indirectly affect the students' motivation to learn, which is the study's limitation and not measured in this study.

D. *AR Development*

The AR application was created by employing the ADDIE Model where all of the processes in the model were implemented to accomplish the AR learning objectives, which are detailed in Table I.

Further explanation of the development of the AR application is illustrated in Fig. 1.

TABLE I: AR APPLICATION DEVELOPMENT PROCESS

Steps	Components
Analyse	a. Learning Problems b. Available Resources c. Learning Theory d. Learning Model e. Observation
Design	a. Application Purpose b. Basic Competencies c. Learning Methods d. Evaluation Instrument e. Measuring instrument
Development	a. Prototype Preparation (Based on analysis dan design) b. Application Development
Implementation	a. Usability Test b. Pilot Study
Evaluation	a. Expert assessment b. Appropriateness

Fig. 1. Process of the AR development.

After all of the AR processes had been developed, the AR application was put through usability and feasibility testing to ensure that it achieved its aim, which is to help students overcome misconceptions and provide a deeper understanding of physics concepts because abstract notions in the concepts can be visualised into concrete ones through the AR simulations. The results of the usability and feasibility test showed that the application fulfilled the purpose of the application's development, which is to help students overcome misconceptions and provide a deeper understanding of physics concepts. The usability test indicators are detailed in Table II.

Additionally, augmented reality was created in this study with the intention of focusing on a specific application of AR, notably in mobile learning. Such an approach would mean that the students are no longer restricted to learning using computers in specific places, and that teaching and learning activities can be carried out in a more dynamic manner. The students can use augmented reality on their mobile phones to help them carry out teaching and learning activities anywhere and everywhere. Usability testing on the AR application was also undertaken to ensure that the software met the competency criteria for comprehending electrical concepts in physics. Output of the AR application is illustrated in Fig. 2.

TABLE II: INDICATOR OF THE USABILITY TEST

	Indicator	Descriptive
AR Application for Student Understanding of Physics Concepts	Materials Design Legibility Visualisation Activities	Suitability Convenience Accuracy Usability

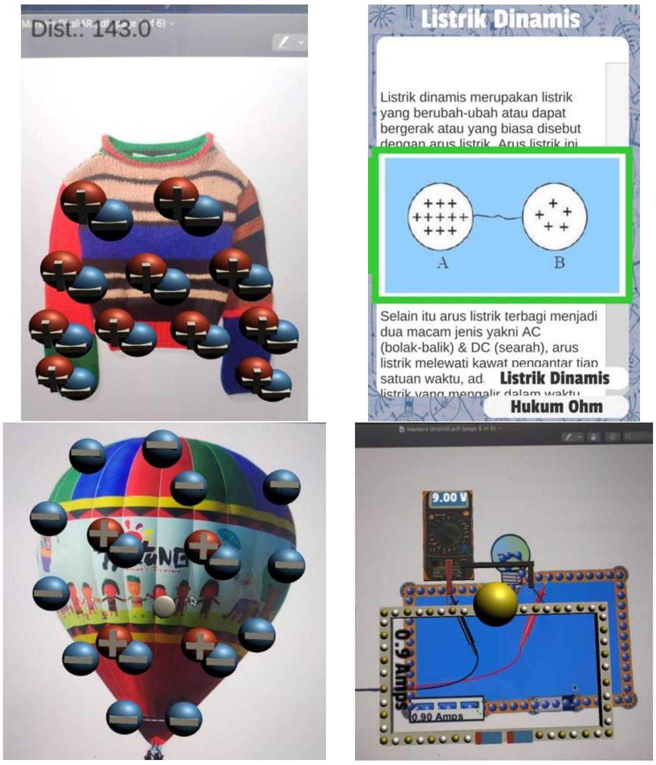

Fig. 2. AR output component.

E. Implementation in the Learning Process

This study was conducted over a six-week (6 x 4 hours) period with the experimental group using the AR application and the control group using the traditional approach (non-AR). Pretest and posttest were employed in this study, with the pretest taking place in class a week before the intervention while the posttest took place after six weeks of intervention. The entire study required eight meetings, including the administration of the pretest and posttest. All the chapters in the AR application were completely discussed, and every student in the experimental group was able to actively participate during the learning and teaching session. The students in the experimental group used the augmented reality application to access learning materials, assignments, exercises, and simulations throughout the learning sessions. Meanwhile, the control group attended the online class as normal, where they were taught using traditional techniques such as teacher-led classes without the use of AR. This meant that the students in the control class attended regular and traditional learning sessions based on the teacher's methods, teaching skills, and online learning preferences. During the class sessions, the experimental group was also given access to operate the AR application independently using their gadgets under the teacher's guidance. The teachers in both classes are trained teachers and both have teaching experience of more than 20 years and have been certified according to the national standard. The learning materials taught in the two classes were the same, namely Static Electricity (Introduction, Coulomb's Law, Electric Fields) and Dynamic (Introduction, Strong Electric Current, Potential Difference, Resistance and Ohm's Law). Students were also assessed using 20 questions that tested their understanding of static and dynamic electricity. The learning process is described in Fig. 3.

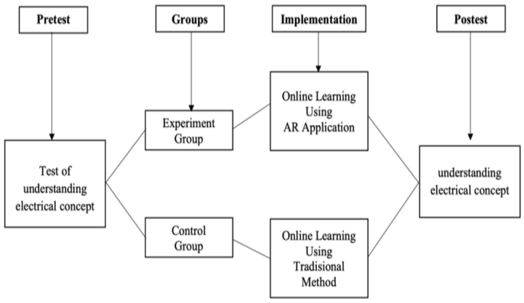

Fig. 3. Research process.

Further explanation of the learning process is also explained in Table III.

TABLE III: INTERVENTION PROCEDURE

Type of Group	Experiment Group	Control Group
Types of Intervention Approach	Use of AR application for learning physics	Conventional / Traditional learning models using the manual book from the ministry as well as the desired learning objectives.
Procedure	Engagement Phase: During this phase, the teacher makes use of students' existing knowledge. The teacher is trying to arouse and develop students' interest in the material to be presented at this point. Exploration Phase: During this phase, the teacher allows the students to engage in activities using the AR application, such as testing predictions and hypotheses through alternate approaches, recording observations, and discussing with other students. Explanation Phase: Students are expected to finish, refine, and develop the topics they have learned. Based on the discoveries in the AR application, students must explain the concepts that they have studied in their own words. Elaboration Phase: The teacher then instructs and let the students investigate and collect data on their own in accordance with the application's flow. Through tasks in the AR application, the students' understanding of the concepts learned are deepened and expanded. The activity directs the students to use what they have learned, to draw connections between concepts and apply what they have learned to new scenarios. Furthermore, the teacher empowers the students to analyse facts and generate preliminary arguments using simulations and resources provided through the application. Evaluation Phase: The teacher allows students to examine the data on their own, and they then come up with tentative arguments based on the simulations and data obtained from the application. In addition, the teacher guides students through an in-depth discussion of the findings. The teacher assesses the progress of the students' comprehension based on completed exercises.	The teacher explains how to formulate electrical problems, particularly those that are difficult to learn and understand. Students are instructed to study the electrical topics using the gathered data which are provided by the teacher. The teacher instructs the students on data analysis processes. Based on the tasks given at the end of the learning session, the teacher analyses the students' understandin g of the topic.

F. Instrument to Test Students' Conceptual Knowledge

The pretest and posttest were created by the researcher by adapting the questions from the senior high school textbooks where the researcher only adjusted the numbers in the problem set and the sentences in the problem for its application to test students' knowledge and understanding. There were 20 multiple choices that the students had to complete before and after the learning process. The questions focused on basic concepts of physics. This instrument was validated by the experts and education officers who were directly involved in the preparation of the questions. The questions were also tested for reliability in terms of scientific appropriateness and consistency. In order to achieve satisfactory reliability, inappropriate problems were revised carefully after review by the panel of experts. In this study, the Cronbach's alpha of comprehension in physics education was 0.742, indicating high reliability [50]. In the trial, the values met the required standards to be used as an instrument. Meanwhile, the 20 problems which were designed via revision and reliability testing were used in the actual data collection; the questions were specifically to test students' understanding of the physic concepts of electricity taught during the learning sessions. The tested problems were assigned before and after the implementation of the intervention procedure through the pretest and posttest to acquire two values for each group. The indicators regarding the questions tested in the study are listed in the Table IV.

The questions were tailored to the content of the AR application used by the experimental group and the textbook used by the control group, allowing the study to use the collected data to discuss students' understanding. The AR application was developed based on the fundamental difficulties and questions that have been previously found in prior studies so that the presence of the AR would be considered as a great potential solution for physics learning since students could observe the simulations and content to improve their understanding of the concepts.

TABLE IV: INDICATOR OF UNDERSTANDING IN THE TEST QUESTION

Subject Matter	Indicator
Static Electricity	a. Charge of Electricity b. Field of Electricity c. Potential Electricity d. Coulomb Law e. Velocity of Electron
Dynamic Electricity	a. Electric Current b. Voltage c. Difference in Electric Potential d. Resistance (Ohm Law) e. Power

G. Data Analyses

In the current study, the analysis methods used were descriptive statistics dan inference analyses. The outliers and extreme data were removed from the data list. Then, each variable was controlled using skewness and kurtosis statistics. Based on a 95% confidence interval, the value of the standard normal distribution would be at the point -2 to +2 [51]. The data results showed normal distribution based on the value which ranged from -2 to +2 with skewness of -0.824 (SE = 0.421) and kurtosis of 1.873 (SE = 0.821) for students' attitude, while the skewness of -0.601 (SE = 0.421) and kurtosis of 1,353 (SE = 0.821) were obtained for the value on understanding of concepts in physics. A paired t-test was used to determine the differences in the level of students' understanding in the pretest and posttest for the groups that used AR and non-AR.

III. RESULT

This research investigated students' understanding of concepts in physics, specifically on the topic of electricity through the use of AR application. Comparison of results were performed between the students who were in the control and experimental groups. Table V presents the percentages of the students' understanding of the physics concepts on electricity for the students in the control and experimental groups before and after the learning sessions. Based on the results, the percentage for the experimental group was higher than the control group. The result suggests that AR can help senior high school students overcome their lack of understanding of physics concepts although the learning is conducted online. Table VI presents the differences in students' level of understanding of the physics concepts related to electricity for both groups before and after the teaching and learning sessions (the intervention). The experimental group showed good achievement in their understanding of the electrical concepts compared to the control group (*M*= 82.03, SD= 5.759). Paired T-test was used to determine student achievement between the experimental group (AR application) and the control group (non-AR). The results showed a significant difference in understanding of the electrical concepts between the students who experienced online learning using the AR application in the experimental group compared to those in the control (non-AR) group (t=-22.665, p<0.000).

TABLE V: THE PRECENTAGE OF RIGHT ANSWERS BEFORE AND AFTER THE LEARNING SESSIONS

	Group	N	Pretest (%)	Posttest (%)
Understanding electrical concept	Experimental	31	58.57	82.03
	Control	29	53.79	60.72

TABLE VI: DIFFERENCES IN LEVEL OF UNDERSTANDING OF THE ELECTRICAL CONCEPTS BETWEEN THE STUDENTS IN THE TWO GROUPS

	Group	N	M	SD	t	p
Understanding of electrical concepts	Experimental Pretest Posttest	31	58.58 82.03	7.796 5.759	-22.665	.000
	Control Pretest Posttest	29	53.79 60.72	8.974 7.181	-4.913	.000

IV. DISCUSSIONS

This study aimed to identify the effects of AR application on high school students' understanding of physics concepts of electricity in which the teaching and learning sessions were carried out online during the COVID-19 pandemic. The results showed that the students in the experimental group obtained a higher score in understanding of physics concepts related to electricity compared to the students in the control group. In this study, the application of AR was designed and developed to teach physics concepts of electricity because of the assumption that electricity is a difficult topic as it contains abstract concepts [13] and previous studies that report students having trouble figuring out how electrical concepts relate to one another [21], [24], [52] in addition to the misconceptions that students often have in the various subtopics of electricity [17]-[21]. These hindered students from gaining deep understanding of the electrical concepts. The use of AR application could help students overcome the difficulty in learning the topic. This is because through AR applications, the abstract concepts of electricity can be visualised into real, concrete concepts using 3D animated programming, allowing students to learn about the concepts better and gain deeper understanding. This newest technology was able to raise the curiosity of the students in the experimental group and attract their interest in learning the electrical lessons compared to the students in the control group. As implemented in this study, the AR application augmented the 2D drawings drawn on paper into 3D images which allowed for more detailed explanation on the abstract concepts in the electricity topic.

In terms of understanding of the topic on electricity, the results showed a large gap between the experimental and control groups. Based on the posttest results, the students from the experimental group who used the AR application demonstrated better understanding of electricity concepts compared to the non-AR control group.

The results obtained showed the potential effect of AR in enhancing students' understanding of the concepts in the topic of electricity especially in understanding the contents related to abstract electrical concepts. The improvement in students' understanding was also shown in the evaluation of learning through AR in the experimental group. The results are in line with the findings in other relevant studies [53]-[55]. There are several factors which indicated that AR affected the students' knowledge. Firstly, AR can support descriptions of the phenomena in 3D form for teaching and learning [56]. In this study, the AR technology-based learning enhanced the student's interaction and encouraged the students' analytical skills. Additionally, the affordances of AR which enabled visualisation increased the students' interest in the learning process because of the uniqueness of AR [57]. Studies have reported that new technologies attract students' attention [7] [58], [59]. Moreover, AR can also make possible visualisation of an object's movements in real-time and this can be repeated to ease understanding [60]. AR can also influence the student's attitude and understanding directly by combining narrative fiction with the real world [61]. Furthermore, AR can also be integrated with gamification to make the learning of subjects more exciting and fun [62]. One of the factors that contributed to better learning of the electrical concepts for the students who experienced AR in the experimental group was that the 3D effect provided a clearer visual perception of the abstract concepts. [63] discussed that the use of AR creates visual 3D patterns that are more realistic and this makes it easier for students to understand difficult abstract concepts compared to 2D patterns because of its advantages of vivid illustrations. AR also allows students to observe a 3D object in 360-degree view, which is more effective for learning compared to observing a 2D object [64] and this can help explain the abstract phenomena in physics clearly to students [65], [66]. In addition, AR technology helps students to explore virtual learning environment via a multimedia digital format such as through text, videos and pictures [61], [67]. Regardless of the 3D features in AR, this advanced technology is impressive [68] and is considered a teaching tool with numerous benefits [69], [70]. Furthermore, [71] discovered that participants who were presented with AR representation of electromagnetism were significantly more effective in developing understanding of the structure of invisible magnetic fields, understanding of the relationship between electric currents and magnetic fields, transferring knowledge about how to make electromagnets, and in completing assignments on time compared to those who did not experience AR.

AR is also considered a media-based learning technology where the students can gain new learning experiences [72]-[74]. The students in the experimental group were more active and motivated to learn their online lessons. Previous studies have shown that AR is a new technology or media-based learning that can raise students' interest and motivation while implicitly supporting and training students analytical problem-solving skills [75]-[77]. In short, the use of AR has a positive effect on student's competency to understand difficult concepts in a lesson.

Additionally, interviews with the students showed that AR was able to solve the problems mentioned previously and develop better understanding of electrical concepts among the students. Through the use of AR, it is possible to visualize the abstract concepts according to the students' level of understanding, enabling and making it possible for students to observe phenomena that they might not encounter in real life. This proves that the use of AR is a problem solver for learning and teaching during this pandemic situation as students are not able to attend physical classes or go out of their home. Moreover, the students who were interviewed also mentioned the suitability, convenience, accuracy, and usefulness of the AR application for learning during the pandemic. They described that the AR application provided convenience for their online learning, especially in helping them overcome misconceptions and gain deeper understanding of the physics concepts.

As mentioned earlier, senior high school students often face learning difficulties in understanding abstract concepts in the topic of electricity. The results of the control group revealed that the students required assistance in learning physics. This factor also affected their behaviour in learning the topic. Most of the students were found to be less attentive and had difficulty in acquiring understanding of the concepts. In the experimental group, the students could find the solution to the problems more easily using the AR application than the students in the control group. It can be concluded that the students in the experimental group gained interest in learning the topic of electricity under the subject of physics as the AR application supported their learning better than the traditional methods used in the online teaching and learning sessions. Similar results from past studies showed that AR is a technology-based learning that can help to clearly describe abstract concepts in sciences [78], [79]. In addition, AR provides memorable experiences for students in gaining knowledge and enhances students' level of understanding, leading to increased academic performances [80]. It was also found that AR technology is able to support learning and teaching, allowing students to understand concepts better during online learning [81]. When compared to the control group, the results also showed that excessive misconceptions among students in learning Physics could be reduced using AR. The students in the experimental group were able to reconstruct the knowledge they gained from their previous thinking errors and rectify the misconceptions resulting from the abstraction of physics concepts as the AR application allowed them to see the visualisation of the abstract concepts. As these are fundamental to their way of thinking about electrical concepts such as static and dynamic electricity, the students' understanding of the concepts thus became increasingly diversified. Other findings revealed that the students in the experimental group gained considerable knowledge, had favourable attitudes, and learned new things. In terms of concepts that are directly related to observations, the fact that the reviewer discovered also illustrates that the usage of this AR tool allows for a considerable transition from inaccurate responses to correct answers. This finding is consistent with a previous study [47] which found that if AR is implemented appropriately, it will be able to rectify student errors. Accordingly, the AR application employed in this study was demonstrated to have a successful instructional design as it achieved the goal for which it was created. The recent social distancing measures implemented around the world necessitate the availability of numerous and diverse online educational materials that can improve student involvement and aid the learning process, and for this reason, AR applications can be one of these materials.

Nevertheless, the fact that the students in the control group also improved their understanding suggests that non-augmented reality experiences can be an effective learning activity for teaching electrical principles. This shows that incorporating augmented reality into a previously successful learning experience may not always be useful to learning. With the condition that AR is a free tool that students can use, students can still gain positive effect on achievement and understanding of the concepts.

V. Conclusion

In the study, Augmented Reality (AR) was investigated through 11th-grade students' attitude and understanding of concepts in physics related to the topic of electricity. AR was found to have enhanced the students' interest in learning of physics and established a positive environment for developing understanding of the concepts, especially since the learning was carried out online during the COVID-19 pandemic situation. The findings may be favourable for the development of AR applications in physics education. This study only involved the topic of electricity. As the AR application in this study was focused only on the topic of electricity, future studies can expand on this and investigate other topics or develop other materials as AR is a technology that is always evolving and easy to acquire. In terms of the research scope, the AR application was used to measure the students' understanding of physics concepts (topic of electricity), while its effects on the knowledge gained were not examined in this study. Thus, a suggestion for future research would be to investigate the effects of AR on the knowledge acquired. The results of this research were limited only to one experimental group in a single school and for one subject. For future studies, the effects of AR on teaching and learning of abstract sciences can be validated through the use of multiple groups which is tested in various areas and using different subjects. During the AR implementations, the application of AR also received a few effects of external factors, including image quality and camera, which can affect the tested results. For this reason, it is suggested that future researchers plan for appropriate steps to reduce these factors to obtain better results.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions

Doni Ropawandi conducted the field research, analysed the data and carried out the literature review. Lilia Halim and Hazrati Husnin guided the research, reviewed, and corrected the article. All authors agreed with the final version of the article.

Acknowledgement

The authors gratefully acknowledge the Faculty of Education, Universiti Kebangsaan Malaysia, for supporting this article.

References

[1] Regulation of Indonesian Government No.21. (2020). Large-scale social restrictions in order to accelerate the handling of Corona Virus Disease 2019 (COVID-19). [Online]. Available: https://setkab.go.id/inilah-pp-pembatasan-sosial-berskala-besar-untuk-percepatanpenanganan-covid-19/

[2] T. Teo, "Pre-service teacher's attitude toward computer use: A Singapore survei," *Australian Journal of Educational Technology*, vol. 24, pp. 413-424, 2008.

[3] R. T. Azuma, "A survey of augmented reality," *Presence: Teleoperators and Virtual Environments*, vol. 6, no. 4, pp. 355–385, 1997.

[4] H. Wu, G. J. Hwang, M. L. Yang, and C. H. Chen, "Impacts of integrating the repertory grid into an augmented reality-based learning design on students' learning achievements, cognitive load and degree of satisfaction," *Interactive Learning Environments,* vol. 26, pp. 1-14, 2017.

[5] R. Brock, "Intuition and insight: Two concepts that illuminate the tacit in science education," *Studies in Science Education*, vol. 51, no. 2, pp. 127–167, 2015.

[6] J. Carmigniani, B. Furht, M. Anisetti, P. Ceravolo, E. Damiani, and M. Ivkovic, "Augmented reality technologies, systems and applications," *Multimedia Tools*, vol. 51, pp. 341-377, 2011.

[7] S. Cai, X. Wang, and F. K. Chiang, "A case study of augmented reality simulation system application in a chemistry course," *Computers in Human Behavior*, vol. 37, pp. 31-40, 2014.

[8] F. Arici, P. Yildirim, S. Caliklar, and R. M. Yilmaz, “Research trends in the use of augmented reality in science education: Content and bibliometric mapping analysis,” *Computers & Education*, vol. 142, pp. 103647-103669, 2019.

[9] D. Sahin and R. M. Yilmaz, “The effect of augmented reality technology on middle school students’ achievements and attitudes towards science education,” *Computers & Education*, vol. 144, pp. 103710-103720, 2020.

[10] C. T. H. Chiang, S. J. H. Yang, and G. J. Hwang, “An augmented reality-based Mobile learning system to improve students’ learning achievements and motivations in natural science inquiry activities,” *Educational Technology & Society*, vol. 17, no. 4, pp. 352–365, 2014.

[11] S. Cai, C. H. Liu, T. Wang, E. R. Liu, and J.-C. Liang, “Effects of learning physics using Augmented Reality on students’ self-efficacy and conceptions of learning,” *British Journal of Educational Technology*, vol. 52, no. 1, pp. 235-251, 2021.

[12] P. L. Thomas, “Student conceptions of equilibrium and fundamental thermodynamic concepts in college physical chemistry,” Ph.D. dissertation, Dept. of Chem. and Biochem., Univ. of Northern Colorado, Greeley, Colorado, USA, 1997.

[13] B. Kollofel, T. H. S. Eysink, and T. D. Jong, “De rol van externe representaties bij onderzoekend leren met computersimulaties,” *Pedagogische Studiën*, vol. 87, no. 1, pp. 51-65, 2013.

[14] S. Çepni and E. Keleş, “Turkish students' conceptions about the simple electric circuits,” *International Journal of Science and Mathematics Education*, vol. 4, no. 2, pp. 269–291, 2006.

[15] N. Korganci, C. Miron, A. Dafinei, and S. Antohe “The importance of inquiry-based learning on electric circuit models for conceptual understanding,” *Procedia-Social and Behavioral Sciences*, vol. 191, pp. 2463–2468, 2015.

[16] J. Li and C. Singh, “Students’ common difficulties and approaches while solving conceptual problems with non-identical light bulbs in series and parallel,” *European Journal of Physics*, vol. 37, no. 6, pp. 065708-065723, 2016.

[17] W.R. Moreu, S. G. Ryan, S. J. Beuzenberg, and R. W. G. Syme, “Charge density in circuits,” *American Journal of Physics*, vol. 53, pp. 552-553, 1985.

[18] D.M. Shipstone, C. V. Rhoenek, W. Jung, C. Karrqvist, J. J. Dupin, S. Joshua, and P. Licht, “A study of students’ understanding of electricity in five European countries,” *International Journal of Science Education*, vol. 10, no.3, pp. 303-316, 1988.

[19] Y. Lee and N. Law, “Explorations in promoting conceptual change in electrical concepts via ontological category shift,” *International Journal of Science Education*, vol. 23, no. 2, pp. 111-149, 2010.

[20] P. David, Maloney, L. Thomas, Okuma, J. Curtis, Hieggelke, and Alan van Heuvalen, “Surveying students’ conceptual knowledge of electricity and magnetism,” *American Journal of Physics*, vol. 69, no.7, 2001.

[21] Ü. Turgut, F. Gürbüz, and G. Turgut, “An investigation 10th grade students’ misconceptions about electric current,” *Procedia Social and Behavioral Sciences*, vol. 15, pp. 1965–1971, 2011.

[22] R. Cohen, B. Elyon, and U. Andganiel, “Potential difference and current in simple electric circuits: a study of students' concepts,” *American journal of Physics*, Vol. 51, no. 5, pp. 407-412, 1983.

[23] P. S. Shaffer, C. Lillian, and M. Dermott, “Research a guide for curriculum development: An example from introductory electricity. Part II: Design of instructional strategies,” *American Journal of Physics*, vol. 60, no. 11, pp. 1003-1013, 1992.

[24] M. R. Stetzer, P. V. Kampen, P. S. Shaffer, and L. C. McDermott, “New insight into student understanding of complete circuit and the conservation of current,” *American Journal of Physics*, vol. 81, no. 2, pp. 134-143, 2013.

[25] D. V. Smith and P. V. Kampen, “Teaching electric circuits with multiple batteries: a qualitative approach,” *Physical Review Special Topics-Physics Education Research*, vol. 7, pp. 020115-1-020115-10, 2011.

[26] Z. Kock, R. Taconis, S. Bolhuis, and K. Graveimejer, “creating a culture inquiry in the classroom while fostering an understanding of theoritical concepts in direct curren electric circuit: a balanced approach,” *International Journal of Science and Mathematics Education*, vol. 13, pp. 45-69, 2015.

[27] J. Garzón, J. Pavón, and S. Baldiris, “Systematic review and meta-analysis of augmented reality in educational settings,” *Virtual Reality*, vol. 23, pp. 447–459, 2019.

[28] S. Cuendet, Q. Bonnard, S. Do-Lenh, and P. Dillenbourg, “Designing augmented reality for the classroom,” *Computers & Education*, vol. 68, pp. 557–569, 2013.

[29] N. Bursztyn, A. Walker, B. Shelton, and J. Pederson, “Increasing undergraduate interest to learn geoscience with GPS-based augmented reality field trips on students' own smartphones”, *Geological Society of America Today*, vol. 27, no.6, pp. 4–10, 2017.

[30] J. A. Frank and V. Kapila, “Mixed-reality learning environments: Integrating mobile interfaces with laboratory Test-beds,” *Computers & Education*, vol. 110, pp. 88–104, 2017.

[31] N. Yannier, S. E. Hudson, E. S. Wiese, and K. R. Koedinger, “Adding physical objects to an interactive game improves learning and enjoyment: Evidence from earthshake,” *ACM Transactions on Computer- Human Interaction*, vol. 23, no. 4, pp. 26-56, 2016.

[32] A. Di Serio, M. B. Ibanez, and C. D. Kloos, “Impact of an augmented reality system on students’ motivation for a visual art course,” *Computers & Education*, vol. 68, pp. 586-596, 2013.

[33] M. Akçayir, G. Akçayir, H. M. Pektaş, and M. A. Ocak, “Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories,” *Computers in Human Behavior*, vol. 57, pp. 334–342, 2016.

[34] M. Akçayır and G. Akçayır, “Advantages and challenges associated with augmented reality for education: A systematic review of the literature,” *Educational Research Review*, vol. 20, pp. 1-11, 2017.

[35] S. Cai, F. K. Chiang, Y. Yuchen-Sun, C. Lin, C, and J. J. Lee, “Applications of augmented reality-based natural interactive learning in magnetic field instruction,” *Interactive Learning Environments*, vol. 25, no. 6, pp. 778-791, 2017.

[36] J. Mart ń-Guti érez, P. Fabiani, W. Benesova, M. D. Meneses, and C. E. Mora, “Augmented reality to promote collaborative and autonomous learning in higher education,” *Computers in Human Behavior*, vol. 51,752–761, 2015.

[37] J. Martin-Gutierrez, E. Guinters, and D. Perez-Lopez, “Improving strategy of self-learning in engineering Laboratories with augmented reality,” *Procedia-Social and Behavioral Sciences*, vol. 51, 832–839, 2012.

[38] I. Efstathiou, E. A. Kyza, and Y. Georgiou, “An inquiry-based augmented reality mobile learning approach to fostering primary school students’ historical reasoning in non-formal settings,” *Interactive Learning Environments*, vol. 26, no. 1, pp. 22–41, 2018.

[39] M. B. Ib áñez and C. Delgado-Kloos, “Augmented reality for STEM learning: A systematic review,” *Computers & Education*, vol. 123, pp. 109–123, 2018.

[40] A. Bates, R. Shifflet, and M. Lin, “Academic achievement: An elementary school perspective,” *International Guide to Student Achievement*, pp. 7-9, New York: Routledge, 2013.

[41] F. Ke and P. Carafano, “Collaborative science learning in an immersive flight simulation,” *Computers & Education*, vol. 103, pp. 114–123, 2016.

[42] E. Gün, “Effects of augmented reality applications on students' spatial abilities,” Master of Science dissertation, Computer Education and Instructional Technologies, Gazi University, Ankara, 2014.

[43] B. Atasoy, E. Tosik-G ün and A. Kocaman-Karoğlu, “Elementary school students' attitudes and motivations towards augmented reality practices,” *Journal of Kırşehir Education Faculty*, vol. 18, no. 2, pp. 435–448, 2017.

[44] M. Sirakaya and E. K. Cakmak, “Investigating student attitudes toward augmented reality,” *Malaysian Online Journal of Educational Technology*, vol. 6, no. 1, pp. 30-44, 2018.

[45] J. H. McMillan and S. Schumacher, *Research in Education: Evidence-Based Inquiry*, ch. 6, Boston: Pearson, 2010,

[46] C. L. Scott, “The futures of learning 3: What kind of pedagogies for the 21st century?” *Educational Research Foresight*, vol. 15, pp. 1–21, 2015.

[47] D. Urbano, M. F. Chouzal, and M. T. Restivo, “Evaluating an online augmented reality puzzle for DC circuits: Students' feedback and conceptual knowledge gain,” *Computer Applied Engineering Education*, pp. 1–14, 2020.

[48] S. Harvey and A. Goudvis, “Strategies that work: Teaching comprehension for understanding and engagement,” Stenhouse Publishers, Portsmouth, 2007.

[49] S. O. Bada and S. Olusegun, “Constructivism learning theory: A paradigm for teaching and learning” *Journal of Research & Method in Education*, no. 6, pp. 66-70, 2015.

[50] S. Arikunto, “*Prosedur Penelitian Suatu Pendekatan Praktek*,” ch. 12, p. 148, Jakarta: Rineka Cipta, 2002.

[51] A. Lyon, “Why are normal distributions normal?” *The British Journal for the Philosophy of Science*, vol. 65, pp. 621–649, 2013.

[52] A. S. Rosentha and C. Henderson, “Teaching about circuits at the introductory level: an emphasis on potential difference,” *American Journal of Physics*, vol. 74, no. 4, pp. 324-328, 2006

[53] S. Macedo, F. A. Fernandes, J. V. Lima, and M. C. V. Biazus, “Learning object to teach the interaction between two magnetics using augmented reality,” *Journal of Educational and Instructional Studies*, vol. 2, no. 4, pp. 1–12, 2012.

[54] Y. Matsumoto, K. Sakamoto, S. Nomura, T. Hirotomi, K. Shiwaku, and M. Hirakawa, “Activity replay system of life review therapy using mixed reality technology,” in *Proc. the International Multiconference of Engineers and Computer Scientists*, vol. 1, Hong Kong: Newswood Academic Publishing, 2012

[55] M. Buesing and M. Cook. “Augmented reality comes to physics,” *The Physics Teacher*, vol. 51, no. 4, pp. 226–228, 2013.

[56] H. M. Lai and C. P. Chen, “Factor influencing secondary school teachers’ adoption blog,” *Computer and Education*, vol. 56, pp. 948-960, 2011.

[57] M. Billinghurst and A. Duenser, “Augmented Reality in the Classroom,” *Computer and Education*, vol. 45, no. 7, pp. 56-63, 2012.

[58] K. R. Bujak, I. Radu, R. Catrambone, B. MacIntyre, R. Zheng, and G. Golubski, “A psychological perspective on augmented reality in the mathematics classroom,” *Computers & Education*, vol. 68, pp. 536–544, 2013.

[59] R. Wojciechowski, and W. Cellary, “Evaluation of learners’ _attitude toward learning in ARIES augmented reality environments,” *Computers & Education*, vol. 68, pp. 570–585, 2013.

[60] N. Minaskan, J. Rambach, A. Pagani, and D. Stricker, “Augmented reality in physics education: Motion understanding using an Augmented Airtable,” *International Conference on Virtual Reality and Augmented Reality*, pp. 116-125, 2019.

[61] M. Dunleavy, C. Dede, and R. Mitchell, “Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning,” *Journal of Science Education and Technology*, vol. 18, no. 1, pp. 7-22, 2009.

[62] E. Klopfer and K. Squire, “Environmental detectives — The development of an augmented reality platform for environmental simulations,” *Educational Technology Research and Development*, vol. 56, no. 2, pp. 203–228, 2007.

[63] A. Dünser, L. Walker, H. Horner, and Bentall, “Creating interactive physics education books with augmented reality,” in *Proc. the 24th Australian Computer-Human Interaction Conference*, pp. 107–114. ACM, 2012.

[64] H. Wu, S. W Lee, H. Chang, and J. Liang, “Current status, opportunities and challenges of augmented reality in education,” *Computers & Education*, vol. 62, pp. 41-49, 2010.

[65] Lu. Kerawalla, R. Luckin, S. Seljeflot, and A. Woolard, “Making it real: Exploring the potential of augmented reality for teaching primary school science,” *Virtual Reality*, vol. 10, pp. 163–174, 2006.

[66] J. Radu and B. Schneider, “What can we learn from augmented reality (AR)? Benefits and drawbacks of AR for inquiry-based learning of physics,” *Computing Systems Proceedings (CHI 2019)*, paper No. 544: pp. 1-12, 2019

[67] F. Bakri, O. Marsal, and D. Muliyati. “Textbooks equipped with augmented reality technology for physics topic in high school,” *JPPPF (Jurnal Penelitian dan Pengembangan Pendidikan Fisika)*, vol. 5, issue 2, pp. 113-122, 2019.

[68] B. Sanii, “Creating augmented reality USDZ files to visualize 3D objects on student phones in the classroom,” *Journal of Chemical Education*, vol. 97, no. 1, pp. 253−257, 2020.

[69] K. H. Cheng and C. C. Tsai, “Affordances of augmented reality in science learning: Suggestions for future research. *Journal Science Education Technology*, vol. 22, no. 4, pp. 449–462, 2013.

[70] M. Pedaste, G. Mitt, and T. Jürivete, “What is the effect of using Mobile augmented reality in K12 inquirybased learning?” *Education Sciences*, vol. 10, p. 94, 2020.

[71] K. S. Krahenbuhl, “Student-centered education and constructivism: challenges, concerns, and clarity for teachers,” *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, 2016, doi: 10.1080/00098655.2016.1191311.

[72] S. Barma, S. Daniel, N. Bacon, M. A. Gingras, and M. Fortin, “Observation and analysis of a classroom teaching and learning practice based on augmented reality and serious games on mobile platforms,” *Intenational Journal of Serious Games*, vol. 2, issue 2, pp. 69-88, 2015

[73] N. F. Saidin, N. D. A. Halim, and N. Yahaya, “A review of research on augmented reality in education: advantages and applications,” *Int Education Studies*, vol. 8, no. 13, pp. 1–8, 2015.

[74] S. Kucuk, R. M. Yilmaz, O. Baydas, and Y. Geoktas, “Augmented reality applications attitude scale in secondary schools: Validity and reliability study,” *Education in Science*, vol. 39, no. 176, pp. 383–392, 2014.

[75] K. Kreijns, F. V. Acker, M. Vermeulen, and H. V. Buuren, “What stimulates teachers to integrate ICT in their pedagogical practices? The use of digital learning materials in education,” *Computers in Human Behavior*, vol. 29, pp. 217–225, 2013.

[76] C. X. Shen, R. D. Liu, and D. Wang, “Why are children attracted to the internet? The role of need satisfaction perceived online and perceived in daily real life,” *Computers in Human Behavior*, vol. 29, no. 1, pp.185–192, 2013.

[77] S. Kucuk, S. Kapakin, and Y. Goktas, ”Learning anatomy via mobile augmented reality: Effects on achievement and cognitive load,” *Anotomical Sciences Education*, vol. 9, issue 5 pp. 411-421, 2016.

[78] H. C. K. Lin, M. C. Chen, and C. K. Chang, “Assessing the effectiveness of learning solid geometry by using an augmented reality-assisted learning system,” *Interact Learn Environmental*, vol. 23, no. 6, pp. 799–810, 2015.

[79] J. Barrow, C. Forker, A. Sands, D. O'Hare, and H. Hurst, “Augmented reality for enhancing life science education,” in *Proc. VISUAL 27, The Fourth International Conference on Applications and Systems of Visual Paradigms*, ISBN: 978-1-61208-724-5, pp. 7-12, 2019.

[80] S. Nuanmeesri, P. Kadmateekarun, and L. Poomhiran, “Augmented reality to teach human anatomy and blood flow,” *The Turkish Online Journal of Educational Technology*, vol. 18, no. 1, pp. 15–24, 2019.

[81] D. Fonseca, N. Marti, E. Redondo, I. Navarro, and A. Sanchez, “Relationship between student profile, tool use, participation and academic performance with the use of augmented reality technology for visualizd architecture models,” *Computers in Human Behavior*, vol. 31, pp. 434–445, 2014.

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