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Augmented reality learning environment to aid engineering students in performing practical laboratory experiments in electronics engineering

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Abstract

In an era where technology is being used more and more in daily life, the potential and effective use of technology is becoming increasingly vital in education. Engineering education necessitates the use of technology to assist students in understanding abstract concepts and principles. Augmented reality (AR) is a technology that can be used to create effective and engaging technology-based solutions and instructional materials. This research aims to develop an augmented reality-based learning experience to teach students about electronics engineering concepts and determine the impact of AR intervention on students' academic achievement levels, learning attitudes toward the subject, and individual attitudes toward AR technology. A quasi-experimental research design was used on 107 first-year engineering students who were grouped into control and experimental groups. The control group consisted of 53 students who learned the fundamentals of electronics using existing techniques, while experimental group consisted of 54 students who learned the same subject using an Augmented Reality-based Lab Manual. The experimental outcomes indicate that the experimental group performed better in the post-test and obtained higher academic scores compared to the control group. In addition, AR intervention has a substantial positive effect on students' learning attitudes. The study also found that students' learning attitudes towards electronics courses and their academic achievement have a significant positive relationship. Additionally, there is a correlation between a student's academic achievement and their attitude toward AR technology. As a result, students who studied using AR technology had a more optimistic perspective about the electronics course and AR technology.

Keywords: Augmented reality, Engineering education, Electronics engineering, Interactive learning environments, Learning attitude

Introduction

Advancements in technology and science have influenced the societal structure and the human life. It has become important to reform the educational environments with enhancements in science and technology to respond to the changing profile of the human being. Potential and successful use of technology is becoming essential in education in an age of rapidly growing use of technology in everyday life. Engineering education require technology intervention which can aid to explain the abstract concepts and principles to the students. It is essential to enhance the students' visualization, particularly in understanding tough and abstract topics, by means of technology to enrich learning environments (Liaw & Huang, 2013; Xia, 2021). Incorporating technology in education also helps students to visualise engineering concepts in a multidimensional way to better interpret knowledge and to stay attentive and concentrated on the subject (Ibanez & Delgado-Kloos, 2018; Liu et al., 2020). Emerging technologies when used in science and engineering education, then students' thinking skills enhances, strengthen their problem-solving abilities, and help them understand their daily life challenging situations. It has become important to merge education technology into engineering subjects and restructure the teaching-learning process as per the needs of the students so that they can learn through practical experiences (Ibanez & Delgado-Kloos, 2018). Augmented reality is a promising technology that provides successful and engaging technology-based solutions and educational materials.

In subjects like Electronics and Electrical Engineering, the students need to have a depth understanding of the circuit connections, current flow, and its direction along with the basic principles of circuit elements to understand the working of the circuits. Generally, students have trouble understanding and grasping complicated abstract concepts which cannot be visualized (Wang et al., 2018). If not understood, they hinder students' understanding of the concept, therefore, harming their attitude towards their subject (Sahin & Yilmaz, 2020). To address these problems, the use of technology and interactive visuals in teaching should be promoted. With the use of interactive and immersive technologies like AR and VR, students can visualize abstract concepts in a better way, and they will be easy to understand. E.g., 3D simulations of the movement of electrons within a circuit can clarify the working principle of a circuit within conventional laboratory settings. As a result, more relevant educational environments can be developed for the students that improve their academic achievement and develop a positive attitude towards learning (Sahin & Yilmaz, 2020). Augmented reality plays a potential role in enhancing teaching-learning environments by providing visualization of abstract concepts, practical observations of a conceptual topic that is otherwise challenging to understand. Considering the importance of AR in educational aspects, this study aims to explore the effect of AR technology on the attitude and achievement of middle school students in learning science.

AR is an emerging and interactive technology that combines real world with virtual objects, thus enhancing the reality (Ibili & Sahin, 2015; Milgram & Kishino, 1994; Singh & Mantri, 2021b). It augments digital content like image, video, 3D models, animation, etc. over the real-world image and displays an enhanced reality to the user (Azuma, 1997; Yilmaz & Goktas, 2017). Due to its potential to enhance reality with 3D virtual objects, it is used in education. AR provides interactive learning environments to the students which further improves their interest and motivation levels (Chen & Tsai, 2012; Su & Cheng, 2014; Erbas & Demirer, 2019). AR can ease the complex and abstract concepts which increases concentration levels of the students (Walczak et al., 2006).

This research work aims to explore the impact of augmented reality technology on the academic achievement level of the first-year engineering students and to analyse their attitude levels towards the basic electronics syllabus and the proposed AR application. The following are the research questions addressed in this study:

1. Is there a substantial difference in academic achievement levels between engineering students who were taught using an AR application and those who were taught using traditional laboratory manual ?
2. Does the use of AR technology for teaching basic electronics to engineering students have any significant impact on their learning attitude?
3. What is the attitude of students towards AR technology who were taught using AR applications?
4. Is there any correlation between the student's academic achievement level, their learning attitude towards basic electronics course and their attitude towards AR technology in experimental groups?

Related work

Literature highlights the usage of AR in engineering education. AR applications are useful for supporting student engagement, transferring learning knowledge, making it tangible by seeing abstract three-dimensional (3D) frameworks, and simplifying difficult topics (Wu et al., 2013). Interacting with 3D objects from various angles and perspectives improves students' spatial abilities and technical skills (Cheng & Tsai, 2013; Kerawalla et al., 2006; Tuli et al., 2021). Several studies have shown that AR-based remote laboratories are effective in electrical engineering (Borrero & Marquez, 2012), information delivery methods (Chiang et al., 2014), mobile applications (civil engineering (Shirazi & Behzadan, 2014), mathematics (Castillo et al., 2015) (Kaufmann & Schmalstieg, 2003), anatomy (Ferrer-Torregrosa et al., 2015) have been successfully designed and implemented, increasing students' motivation, curiosity, in-depth understanding, and spatial interpretation. Furthermore, AR delivers an instant reaction via a real-time interface, allowing learners to study according to their needs (Bujak et al., 2013; Yuen et al., 2011; Tuli & Mantri, 2020a, 2020b).

Wang and Chi (2012) analysed the impact of AR on academic achievement and satisfaction levels of the students. Their study showed that students who learnt through AR performed better and showed higher satisfaction levels than other students. Abdusselam (2014) emphasised on the application of augmented reality in physics concepts like magnetism to the students is highly beneficial. In addition, many studies highlight that the students of all grade levels enjoyed learning through AR and showed a very constructive relationship between attitudes of students and Augmented Reality learning applications. Yildirim (2016) performed a study to explore the impact of AR on motivation, academic achievement, attitude, and problem-solving ability of students. In a study, Martin Gutierrez et al. proposed an AR application which improved spatial abilities of the students. The students loved the application and found it attractive, easy to use and a very useful learning method (Gutierr et al., 2010). In another study, Andujar et al. proposed an augmented remote laboratory (ARL) for industrial and computer engineering students.

The analysis showed that the use of ARL improved learning outcomes of the students as compared to traditional methods (Andujar et al., 2010).

() developed a VR learning environment for operating electronics engineering equipment and analyzed the effectiveness of using Virtual Reality on knowledge, cognition, and motivation levels of engineering students. The VR system was deployed on 65 engineering students and experimental results suggest that the use of VR technology had a substantial constructive impact on the knowledge, learning motivation, and cognition of students. The design and development of virtual content are essential in VR and AR environments as they provide additional information to the user. So, it is crucial to design the virtual content accurately as it can directly impact the user experience and student performance. In another study by Faridi et al. (2020) the authors developed an Augmented Reality based educational environment to teach basic physics concepts like electromagnetic waves, Fleming's rule, magnetic field, etc. After experimenting with the learning environment on 80 engineering students, they analyzed that the AR-based approach improved the critical thinking, visualization, and understanding of the students.

If we summarize the literature on the use of AR in education, the factors like interest, motivation, attitude, and achievement level of students are often considered. Generally, the studies investigate one factor. Only a few studies discuss multiple factors. In addition, there are not many studies that discuss the impact of AR in electronics engineering. There are limited studies highlighting the factors and pedagogical methods to be considered while developing AR applications for engineering education. Some factors to be considered include learner training to use and model AR, visualisation, creative content, increased level of perception with students involvement, training of the developers regarding the technical concepts, readiness to update or create new content within the existing app (customizability) (Nesterov et al., 2017; Henderson & Feiner, 2007). Other factors considered while developing AR engineering education include perceived usefulness (Alvarez et al., 2017), satisfaction (Contero et al., 2012), usability (Cubillo et al., 2012), motivation (Cheng et al., 2018), enjoyment (Matcha & Rambli, 2012), technology acceptance (Ibáñez et al., 2016; Alvarez-Marin & Velazquez-Iturbide, 2022). The designers need to identify the methods to incorporate functional features of perceptual association through integrating virtual objects to achieve digital elements that interact with the real environment more naturally (Alvarez-Marin & Velazquez-Iturbide, 2022).

Research methodology

This segment explains the methodology followed in the study. It consists of participant details, experiment design and measuring instruments used in the study. The university's Vice-Chancellor gave written permission for the current study to be done on engineering students. A detailed proposal was submitted, mentioning the purpose of the study, experimental method, instruments and technologies used in the investigation, and possible outcomes of the study. The participants were first-year engineering students who volunteered to participate in the study. They were asked to fill out a form to give their consent and demographic information to participate in the study. The data was collected in the university's electronics laboratory.

Participants

In this research study, two classes of first-year engineering students were selected and a total of 107 engineering students participated voluntarily. A pre-test with 10 basic questions related to the basic electronics course was conducted to compare the existing knowledge level of both the classes prior to the intervention. An independent sample t-test was used to compare the scores. The mean value of the pre-test score for first class was $M = 6.92$ with $S.D. = 3.21$ and mean value of pre-test score for second class was $M = 6.58$ with $S.D. = 2.91$. The pre-test findings demonstrate that the mean scores of the two groups are not statistically different. So, after the pre-test, one class was assigned as the experimental group and trained using AR-based learning system. Second class was assigned as the control group and taught using the traditional teaching approach. The students of both groups have very less or no knowledge about AR technology. Table 1 presents the demographic distribution of the participants:

Experiment design

This research work uses a quantitative analysis method i.e., quasi-experimental research framework. This framework is deployed in the studies where the control and experimental groups are created with pre-existing classes and not selected randomly (Fraenkel & Wallen, 2000; McMillan & Schumacher, 2010). In this study, a pre-test is used to compare the knowledge and academic achievement level of control and experimental groups prior to teaching intervention. In the first year of engineering, students' study about basic electronics and this study is carried out in the basic electronics course. The experimental group was taught about basic electronics with AR based Learning Manual (ARLM) for 4 weeks, while the control group was taught using the traditional laboratory manual. After the teaching intervention, a post-test was carried out for both groups to identify the impact of teaching pedagogy on the knowledge development of the students.

After the post-test, students from both groups were asked to complete a questionnaire about their attitude towards basic electronics course. In the end, students in the experimental group were invited to complete a questionnaire on their attitudes toward augmented reality technology. The experimental group was asked their experience and opinion about the AR technology. Figure 1 shows the experimental design procedure of the study.

Data collection and instrument design

In this study, the academic achievement and attitude of the students of both the groups were evaluated using "Academic Achievement Test" and "Attitude Test (towards subject)". Another test, Attitude test towards ARLM was steered to analyze the attitude of students of experimental groups towards the AR technology.

Table 1 Demographic characteristics of the participants

Groups	Male	Female	Total
Experimental group	29	25	54
Control group	32	21	53
Total	61	46	107

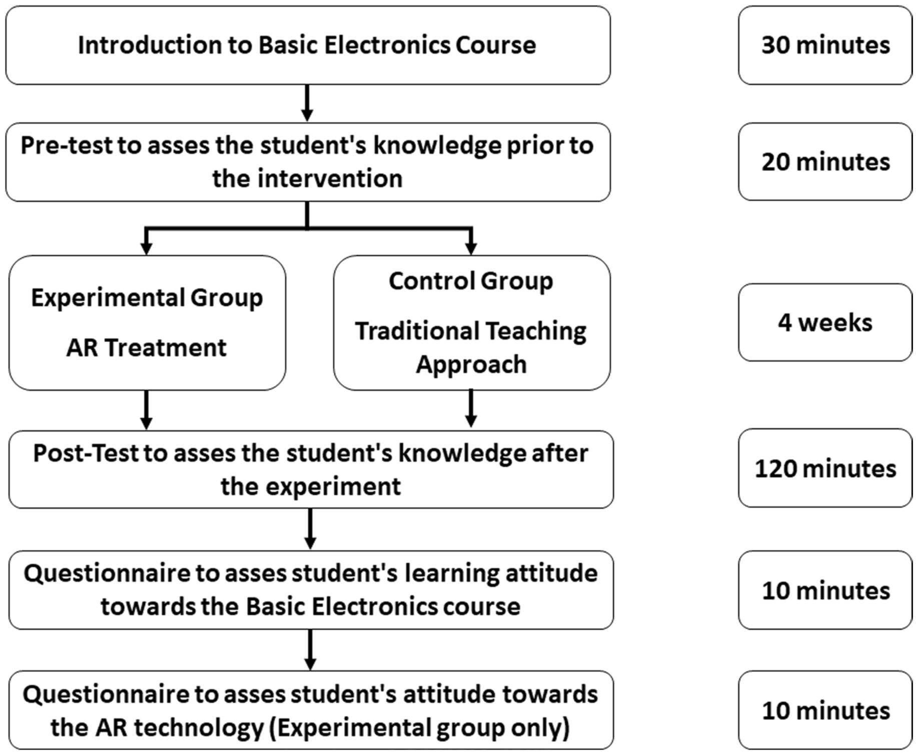


Fig. 1 Experimental design

Academic achievement test

The academic achievement test was used to analyze the knowledge of students before and post to the teaching intervention. A pre-test was conducted before the teaching intervention to determine the knowledge of students. It comprised 20 MCQs (multiple-choice questions) related to the basics of electronics engineering. The maximum score for the pre-test was 20 and students had 20 min to finish the test.

A post-test was designed to evaluate the knowledge gained by the students after the teaching intervention. The post-test was designed using Bloom's taxonomy and it consists of 3 types of questions: multiple-choice questions (20 questions of 1 mark each), short answer subjective questions (10 questions of 3 marks each), and problem-based questions (5 questions of 10 marks each). The post-test had a maximum of 100 points and students were given 120 min to complete the test. A panel of five professional educators with more than 10 years of teaching experience in electronics engineering created both the pre-test and post-test. The questionnaires were finalized after the validation by all five subject teachers. Both the pre-test and post-test were designed using the Bloom's taxonomy and further mapped with the course objectives of basic electronics engineering (Jones et al., 2009; Kumar et al., 2022). The questions are based on the six levels of Bloom's taxonomy: Remember (R), Understand (U), Apply (P), Analyze (N), Evaluate (E), and Create (C).

Questionnaire for learning attitude

The learning attitude of the students towards the basic electronics subject was evaluated using a survey questionnaire proposed by (Hwang et al., 2013). It has seven items to which students shall answer on a five-point Likert scale. It consists of items like: "I think learning about basic electronics is interesting and valuable", "I would like to learn more and observe more in the electronics course", "I will actively search for more information and learn about electronics course", "It is important for everyone to take the electronics course". The Cronbach's alpha for the survey questionnaire was 0.729, indicating that it was consistently reliable.

Questionnaire for attitude towards AR technology

The survey questionnaire proposed by (Kucuk et al., 2014) was utilized to analyze the attitude of students towards the use of AR technology. The questionnaire comprises 15 items related to anxiety, willingness, and satisfaction. Anxiety referred to the students' hesitation in using AR technology. Higher anxiety level means the students had a negative attitude towards using AR while learning. Willingness referred to the interest and aspiration of the students to use AR in future. Satisfaction referred to the usefulness (ease of use) of AR in their learning process. Higher levels of willingness and satisfaction reflects positive attitude of students towards AR. Students used a five-point Likert scale that ranged from 1 (Strongly Disagree) to 5 (Strongly Agree). The Cronbach's alpha of the questionnaire was 0.837 presenting good reliability of the scale.

Learning materials

Traditional laboratory manual

The traditional lab manuals that are used in electronics laboratories have limited and fixed learning content. The lab manual is mainly based on text information and images. It follows a standardized syllabus, and the same content is being followed for several years. Although the content and syllabus are being discussed and finalized by many subject experts, those lab manuals are not interactive and immersive which makes them repetitive and monotonous for the students. The experiment procedure written in the manuals is taught in the respective lab, which makes it unnecessary to go through them again unless there is new information. Students don't read and go through them often unless it is mandatory for them. Students prefer going through YouTube videos or other digital media for the same information. They may find new and interesting information/content from videos or other interactive content that can help enhance their knowledge.

Augmented reality based laboratory manual (ARLM)

Nowadays, Augmented Reality and Virtual Reality have emerged in the field of education giving all together with a new and innovative experience to the students as well as teachers. We chose to develop an AR-based Laboratory Manual (ARLM) for teaching the basics of electronics engineering to first-year engineering students. This subject is considered as the base for the electronics engineering students so that they understand further difficult concepts throughout their engineering. It requires practical knowledge which becomes difficult when there is limited infrastructure compared to the number of students. In addition, it becomes challenging for one instructor to handle the queries or doubts of all students when multiple set of students are performing practical experiments during the laboratory session. Also, sometimes it is dangerous to perform some experiments as they may lead to shock or damage of equipment due to short circuit. Therefore, the knowledge of the students remains limited as they are restricted to perform practical experiments during laboratory sessions. So, there is a need of self-guided learning environment which helps the student to perform practical experiments on their own. In this study, an AR-based Laboratory Manual (ARLM) is developed that provides 3D visualization of the laboratory experiments and allows students to interact with the learning environments. ARLM is an active learning environment and permits the students to interact with the virtual circuits and manipulate them to see how it works if they change the input voltages. In traditional classroom study, students are bound to perform the same experiments as per the directions of the instructor but using ARLM they can try performing the experiments on their own. Also, they can try to give the different inputs in the AR environment without causing the damage to the equipment. The AR environment will also give text instructions to the students about the experiment procedure.

System setup A handheld device (phone or tablet) or a head-mounted display is used in this setup. The tablet acts as a user interface for the student for performing experiments. There is a marker-based lab manual just as the magic book. Markers aid the manual design, thus giving a virtual experience of each experiment. A simple marker is a black and white image containing a pattern or a 2D barcode (Patkar et al., 2013; Tuli & Mantri, 2015). These markers can be scanned by the camera of our handheld device in which the software of marker detection is installed. As a result, the video, 3D models or an image placed at the position of the respective markers would be viewed on the device.

Working The markers that are in the manual are scanned with the hand-held device (tablet). Each marker is linked to an electronic component (breadboard, IC, resistor) and the experiment (in lab manual). The user can just scan the marker placed in the manual. The software/application captures the image and then combines it with the virtual graphics. The virtual graphics are displayed on the user's tablet providing the user an immersive AR experience as mentioned in Fig. 2.

The ARLM consists of three key features:

i. Introduction to electronic components
ii. Experiments
iii. Question/Answers
iv. Introduction to electronic components:

Before performing experiments, the students must understand all the components that are present in the electronics laboratory such as ICs, Resistors, LEDs etc. The

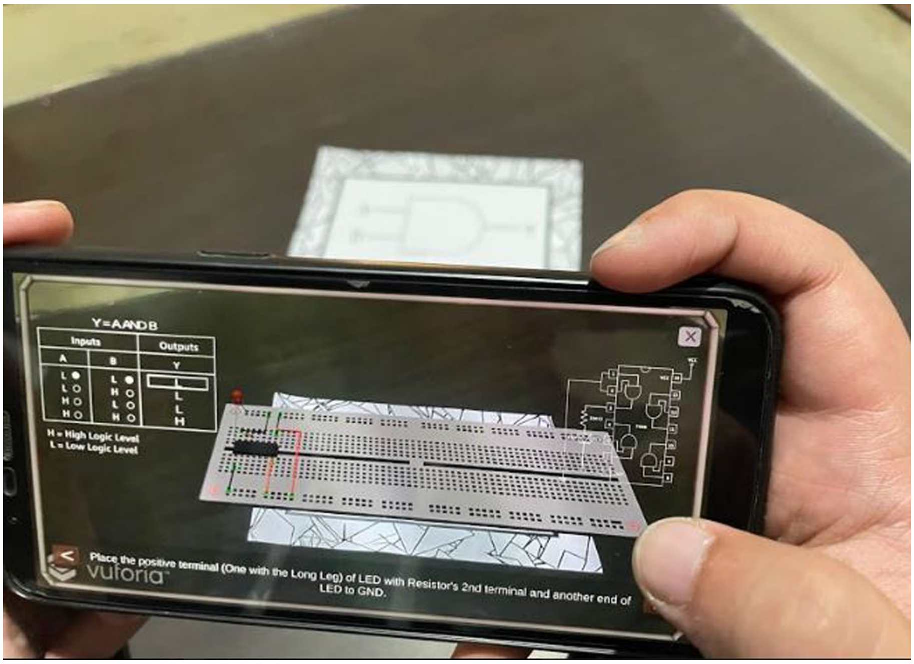


Fig. 2 AR-based laboratory manual

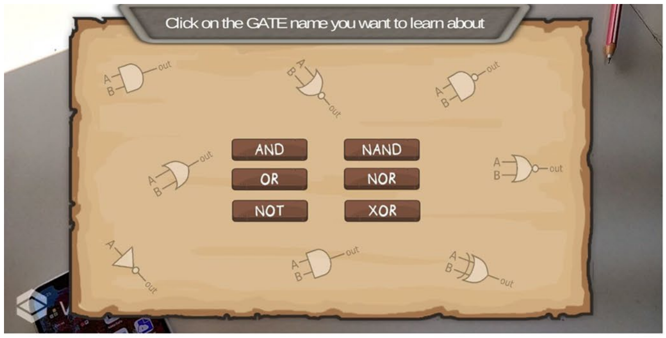
same thing can be taught by the teachers. The difference is that when the students see the components working visually, they would comprehend and remember it for a longer period of time.

The user can view the component in AR environment, read its specifications and understand the description of the component. The user can further choose any one of the three options: Information, Specifications, Classifications.

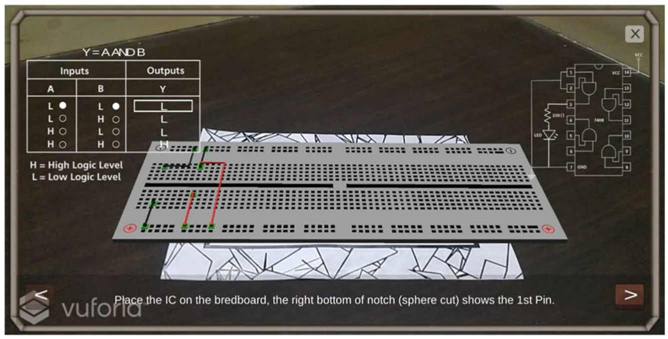
a. Info: It gives the basic introduction about the component.
b. Specifications: It gives the detailed technical specifications of the component.
c. Classifications: It gives the classifications (if any) of the respective component. For e.g. There are different types of ICs that can be used. So, the user can know about all of them.
d. Experiments

ARLM provides the detailed stepwise instructions of each experiment performed in the lab as given in traditional lab manuals. The difference here would be when the user scans the marker placed beneath the experiment, an explanatory animation of the experiment would be played on his handheld device. The users can pause/play/stop the animation as required. In addition, the user can pause the animation and try to change the connections in the animation to check how the respective circuit would respond to the changes done. It would give him an interactive experience with the circuits which he may or may not be able to perform in an actual laboratory due to associated risks or hardware limitations.

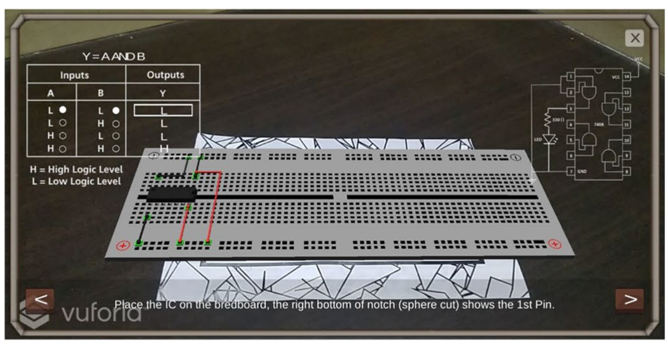
The following steps will explain the workflow of AND gate experiment:



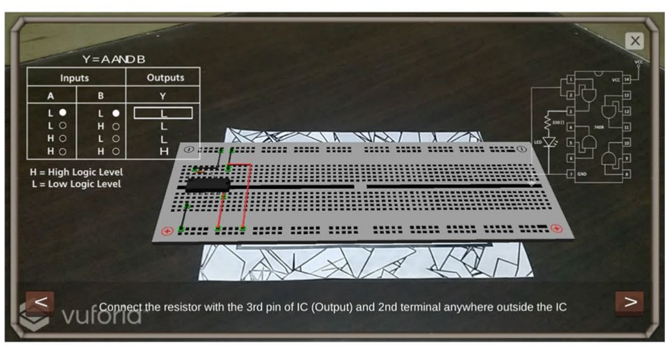
(a). Main page of AR application



(b). AND Gate Experiment in AR application

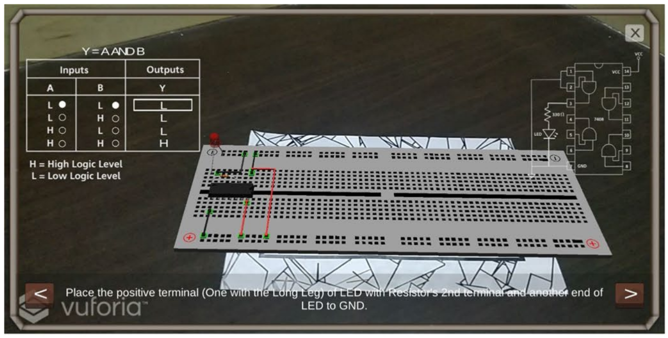


(c). Placing the IC of AND Gate on breadboard in AR application

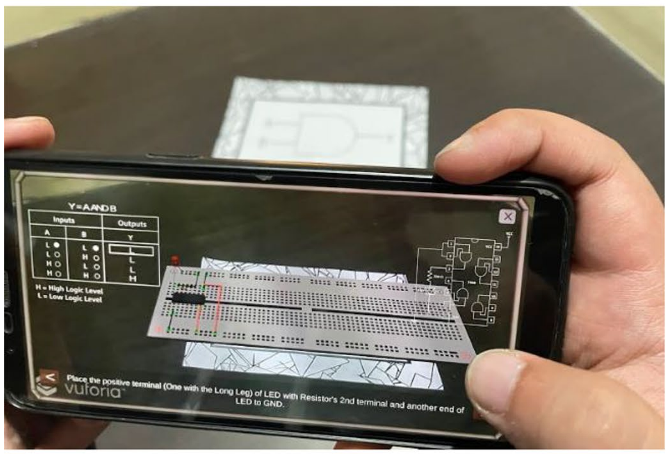


(d). Connecting the resistor with AND Gate in AR application

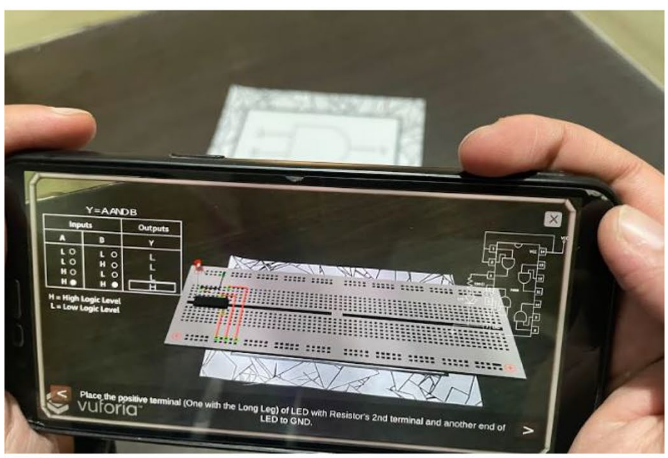
Fig. 3 **a** Main page of AR application. **b** AND gate experiment in AR application. **c** Placing the IC of AND Gate on breadboard in AR application. **d** Connecting the resistor with AND Gate in AR application. **e** Connecting the LED with AND Gate in AR application. **f** LED is off when the user selects (LOW, LOW) as the input in AR application. **g** LED glows when the user selects (HIGH, HIGH) as the input in AR application



(e). Connecting the LED with AND Gate in AR application



(f). LED is off when the user selects (LOW, LOW) as the input in AR application



(g). LED glows when the user selects (HIGH, HIGH) as the input in AR application

Fig. 3 continued

1. Figure 3a shows the main page of experiments on the topic "GATE" is as follows:
2. Figure 3b shows the experiment page of AND Gate as selected from the main menu. There are stepwise instructions written at the bottom of the screen with forward and backwards arrows. The forward arrow takes the user to the next step of the experiment and backward arrows shows the previous step of the experiment. The truth

table and circuit diagram of the respective gate is also displayed in parallel. Both are interactive and change according to the connections made by the user.

3. Figure 3c–e shows the steps of the experiment that include placing the IC on breadboard, connecting the resistor, and placing the LED.
4. After the connections are made, the user can change the values of the truth table. For e.g. user can try to see what happens in "AND Gate", if both the inputs are low. The results would be visible to the user as soon as inputs are changed. In addition, the circuit diagram of the connection would also change according to the new connections made. Figure 3f shows that the LED is off when the user selects (LOW, LOW) as the input. 3 g shows that the LED glows when the user selects (HIGH, HIGH) as the input. The changes in the experiment, truth table and circuit diagram are displayed to the user simultaneously on the mobile screen.
5. Practice quiz

ARLM provides another useful feature of virtual quiz at the end of each experiment asking 2–3 questions regarding the experiment to evaluate the user understanding about the experiment. The user can answer the questions on his own or scan the associated marker to view the options.

Result analysis

This research work analyses the impact of AR on the academic achievement levels of students in basic electronics courses. Also, on the student's learning attitude and their attitude towards the AR technology. The data is collected from the students during the experimental study and calculated in the SPSS software tool to draw out conclusions. The difference in academic achievement and learning motivation between the two groups was determined using an independent sample t-test. The Pearson correlation was deployed to find out the correlation between academic achievement level, learning attitude of students and their attitude towards AR technology.

Is there a substantial difference in academic achievement levels between engineering students who were taught using an AR application and those who were taught using traditional laboratory manual?

The substantial difference in academic achievement levels of students from both groups was determined using the independent sample t-test. Table 2 shows, the experimental group's mean of pre-test score for academic achievement is 6.92 and mean value of pre-test score for control group is 6.58 with a p-value of 0.574. The

Table 2 t-test analysis of Pre-test of students' academic achievement levels

Group	N	Mean	S.D	*t*	df	*p*-value	95% confidence interval of the difference	
							Lower	Upper
Experimental group	54	6.92	3.21	0.574	105	0.567	− 0.83655	1.51859
Control group	53	6.58	2.91					

Table 3 t-test analysis of Post-test of student's academic achievement levels

Group	N	Mean	S.D	*t*	df	*p*-value	Cohen's d	95% confidence interval of the difference	
								Lower	Upper
Experimental group	54	79.68	6.71	8.034	105	0.000	1.55	7.59330	12.56952
Control group	53	69.60	6.25						

Table 4 t-test analysis of students' attitude towards electronics subject

Group	N	Mean	S.D	*t*	df	*p*-value	Cohen's d	95% confidence interval of the difference	
								Lower	Upper
Experimental group	54	3.73	0.48	4.692	76.695	0.000	0.91	0.39379	0.97458
Control group	53	3.05	0.94						

pre-test outcomes signify that there is no difference in the academic achievement levels of both groups prior to the teaching intervention. So, post-test analysis can be used to determine the impact of teaching intervention on the academic achievement levels of the students.

Table 3 presents the t-test analysis of post-test scores. As shown in Table 3, The experimental group's mean post-test score is 79.68, while the control group's mean post-test score is 69.60, with a p-value < 0.01 which suggests that there is a difference in the academic achievement levels of both groups. The outcomes of the post-test signify that the students of the experimental group showed better performance and showed higher levels of academic achievement as compared to control group students. So, AR intervention has a significant positive influence on the academic achievement level of students. Cohen's d value is 1.55 showing larger effect size.

Does the use of AR technology for teaching basic electronics to engineering students have any significant impact on their learning attitude?

An independent sample t-test was deployed to determine the impact of AR technology on the learning attitude of students towards basic electronics courses. Table 4 shows, the mean value of learning attitude of the experimental group is 3.73 and the mean value of learning attitude of the control group is 3.05 with a p-value < 0.01 which recommends a significant difference in the learning attitude of students of both groups. The experimental outcomes signify that student of the experimental group have a better learning attitude towards basic electronics courses in comparison to students of control groups who learned through conventional methods. So, the use of AR technology for teaching basic electronics has a constructive impression on the learning attitude of students. Cohen's d value is 0.91 showing large effect size.

Table 5 Descriptive Statistics of Attitudes towards AR applications

Parameter	N	Mean	S.D	Minimum	Maximum
Use Satisfaction	54	4.46	0.497	3.29	5.00
Use Anxiety	54	1.40	0.414	1.00	2.67
Use Willingness	54	4.64	0.407	3.50	5.00

Table 6 Correlations between Academic Achievement, Learning Attitude towards the basic electronics course and Attitude towards AR technology

		Academic Achievement (Post-Test)	Learning Attitude towards basic electronics course	Attitude towards AR Technology
Academic Achievement (Post-Test)	Pearson Correlation	1	0.512**	0.617**
	Sig. (2-tailed)		0.000	0.000
	N	54	54	54
Learning Attitude towards basic electronics course	Pearson Correlation	0.512**	1	0.208
	Sig. (2-tailed)	0.000		0.131
	N	54	54	54
Attitude towards AR Technology	Pearson Correlation	0.617**	0.208	1
	Sig. (2-tailed)	0.000	0.131	
	N	54	54	54

** Correlation is significant at the 0.01 level (2-tailed)

What is the attitude of students towards AR technology who were taught using AR application?

The attitude of experimental group students towards AR applications was calculated using descriptive statistics. Table 5 presents that the students found the application usable and easy to use posed ARLM (M = 4.46, SD = 0.497). They were happy and excited to use it in future (M = 4.64, SD = 0.407). Also, they did not show any form of anxiety while using ARLM (M = 1.40, SD = 0.414). The descriptive statistics show that experimental group students have a positive attitude towards the use of AR technology for learning about basic electronics.

Is there any correlation between the student's learning attitude towards basic electronics course, attitude towards AR technology and their academic achievement level in the experimental group?

The correlation between the students' learning attitude towards basic electronics course, attitude towards AR technology and their academic achievement level was analyzed using Pearson correlations. As shown in Table 6, the result shows a moderate positive relationship between the learning attitude of students towards basic electronics course and their academic achievement ($r = 0.512$, $p < 0.01$). Also, there is a moderate positive relationship between the student's academic achievement level and their attitude towards AR technology ($r = 0.617$, $p < 0.01$). There is no significant relationship between the student's learning attitude towards basic electronics course and their attitude towards AR technology.

Discussion

This study aimed to determine the impact of AR on the student's academic achievement and their learning attitude towards basic electronics course for first-year engineering students. Also, the student's attitude towards the proposed Augmented Reality based Lab Manual (ARLM) was analyzed. Also, this experimental study explored the correlation between the students' academic achievement, learning attitudes towards basic electronics course, and their attitude towards AR technology. The subject "basic electronics" of electronics engineering was chosen as it is one of the most important subjects which is the foundation course of electronics engineering. The basic electronics course involves abstract concepts which need to be explained practically as generally students face difficulty in understanding the course through traditional teaching approaches (Chiang et al., 2014). AR technology has the capability to provide better visualization and spatial explanation to the students. So, an AR-based laboratory manual (ARLM) was developed which provides 3D visual explanation of all the electronic components to the students. ARLM provides basic experimentation by providing interactive and enhanced learning experiences to the students.

In comparison to the students in the control group, the experimental group performed better in the post-test and obtained higher academic scores. So, the use of AR technology has a significant positive effect on the academic achievement level of the students. The obtained results follow and support the related studies (Cai et al., 2014; Liu et al., 2007; Sin & zaman, 2010; Vilkoniene, 2009; Hung et al., 2016; Chen et al., 2020). AR has a positive effect on the academic achievement level of students due to many possible reasons. Firstly, the students get excited and inquisitive to learn with a new technology (Yilmaz & Goktas, 2017; Mahadzir & Phung, 2013).. This makes them actively participate in their classroom activities which further improve their understanding. It was observed during the learning activity that students were actively participating in the classroom and completing all the experiments of the manual (Kreijns et al., 2013; Shen et al., 2013; Delello, 2014; Zhang et al., 2014). Secondly, AR is considered as a magic by the students due to its capability of augmenting virtual objects in the real world. AR provides practical implementation of the abstract concepts providing more meaningful and comprehensive learning (Kerawalla et al., 2006; Bujak et al., 2013; Bressler et al., 2018). AR provides three-dimensional visualization of abstract concepts to the students which also enhances their spatial abilities which further improves their understanding of the subject. It also grabs their attention, hence contributing to their knowledge and achievement levels (Bujak, et al., 2013; Wojciechowski & Cellary, 2013). The capability of AR technology to provide interaction with 3D objects in the real world makes it more effective than traditional educational methods (Kerawalla et al., 2006). Also, the learning content when merged with AR technology is more beneficial and effective to use (Matcha & Rambli, 2013; Medicherla et al., 2010; Chang, 2013; Perez-Lopez & Contero, 2013; Sin & Zaman, 2010; Tuli & Mantri, 2020a, 2020b). The academic performance of experimental group students was improved as they got more engaged with AR content. Hence, it can be concluded that AR has significantly improved the academic performance and achievement of the engineering students.

This study also analyzes the impact of AR technology on the learning attitude of students towards their subject. The experimental results show that participants in the experimental group who learnt using AR had a better learning attitude than students in the control group who learned through traditional methods. The experimental outcomes corroborate with the similar studies done by the researchers (Cai et al., 2014; Delello, 2014; Wojciechowski & Cellary, 2013; Gargrish et al., 2021). The literature revealed that the students get attracted towards the new technologies as they develop their interest and motivate them to learn. AR improves student motivation levels as learners consider learning with AR as more fascinating and delightful. The characteristics of AR technology like novelty, interesting, engaging, and fascinating supports the experimental outcomes (Wojciechowski & Cellary, 2013) (Chen et al., 2011).

While learning electronics engineering students face challenges in understanding abstract concepts like circuit diagrams, electronic connections, current flow, and direction, etc. Students sometimes feel irritated and annoyed when they face difficulty in understanding the concepts (Chiang et al., 2014). Students of the control group were not given any assistance in learning while experimental group learned with the help of AR, which helped them understand their lessons/topics in a better way. Therefore, students of the experimental group had a favourable attitude about the deployment of augmented reality technologies for learning. This observation supports the literature stating that AR is a beneficial tool for education that simplifies abstract concepts (Walczak et al., 2006; Somyurek, 2014; Faridi et al. 2021).

This study also examines the correlation between student's learning attitude towards basic electronics course, attitude towards AR technology and their academic achievement level in experimental group. There is a significant positive relationship between the learning attitude of students towards basic electronics course and their academic achievement. Also, there is a positive relationship between the student's academic achievement level and their attitude towards AR technology. Therefore, the students who learned with AR technology exhibited better learning attitudes towards the basic electronics course and AR technology.

Conclusion

The use of Augmented Reality based teaching material in electronics engineering helps in better understanding and performance of students and hence improves their academic achievement and attitude towards learning. This study examines the impact of AR-based laboratory manuals on the academic achievement and attitude of students. The experimental results shows positive influence of AR intervention on student's academic performance and learning attitude.

The following factors need attention on using AR as a pedagogical tool on a large scale. Smartphones or tablets with cameras are required to run AR applications as AR applications can easily run-on smartphone processors. Nowadays, most students carry smartphones with them, which will be an added advantage. The significant challenge for deploying AR on a larger scale is teachers, educators, and students' lack of training and experience with AR applications. So initially, basic training is required to familiarize the teachers, educators and students with the AR application and its working.

Another challenge is to develop a unique learning experience with AR and its content validity. AR applications can provide an immersive learning experience to students and teachers. But the development of AR applications requires professionals who are proficient in game development, 3D designing, animation and rendering. Development of AR applications and games requires professional licensed software tools such as Unity 3D, Maya, Blender, and Adobe photoshop. So, financial support is necessary to deploy AR as a pedagogical tool on a larger scale. AR technology has an enormous capacity to provide quality education and interactive learning experience to the students in online mode. In the COVID era, online teaching was preferred to give learning to the students. This study recommends that academic institutions and organizations financially support the teachers and education researchers for developing unique learning experiences using AR technology and deploying it on a larger scale.

One limitation of the present study is the relatively short duration of the teaching intervention. Due to the limited content of the AR application, students have used it for four weeks only. In future, more topics of electronics engineering will be added to the AR-based Learning Manual. Future studies can be conducted to analyze the impact of AR technology on memory retention of students to determine whether the achieved knowledge through AR persists for a longer time or not. AR can be further used in other domains of education also.

Abbreviations

3D	Three dimensional
AR	Augmented reality
ARLM	Augmented reality-based laboratory manual
M	Mean
S.D.	Standard deviation
VR	Virtual reality

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NT and GS have deployed the AR system on students, collected the relevant data, and analyzed the results, AM has designed the experiment and provided the guidance in executing the same, SS has developed the AR application and provided technical support.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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