# AR Application for Learning Electrical Circuits

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**Abstract.** In the learning of the exact sciences, especially those related to engineering, there has been difficulty in achieving effective learning in the complex topics that these areas of knowledge include, affecting the motivational state of the students. Currently, some applications are based on the use of technology as a learning management tool. However, not all available tools are being used to better capture students' attention. This work aids with the learning of the topic "Electric circuits" in first-grade engineering students by promoting learning, understanding, and application of the benefits that augmented reality technology provides. In addition to being able to change content to each student's learning pace, the fuzzy logic technique based on student interaction allows for content adaptation.

**Keywords:** augmented reality, fuzzy logic, intelligent learning environments.

## 1 Introduction

Recently, the use of new technologies aimed at improving the teaching-learning process of students has been increasing considerably, especially in Science, Technology, Engineering, and Mathematics (STEM) from preschool to post grade [1]. Every day, people use mobile devices increasingly often, allowing them to perform various tasks such as making a video call or making an electronic transaction, with smartphones having the highest frequency of use [12]. The increment in the demand for the use of a mobile and the increase in the hardware capacity of the devices has contributed to the integration of technologies, such as 3D virtual environments, virtual reality, and augmented reality, which have proven to be effective to promote learning [4].

Augmented reality (AR) is a technology that complements user's perception of the real world through a contextual layer of three-dimensional information [2], giving the user the possibility of real-time interaction with the over posed digital elements, allowing the user the possibility of visualizing abstract and complex elements, difficult to imagine. On the other hand, artificial intelligence has impacted various areas, and education is no exception, whether it is applying computer vision to evaluate tasks or articles, evaluating students and teachers through adaptive learning methods or personalized learning approaches, or create interactive learning environments through facial recognition, virtual laboratories, augmented or virtual reality [13]. The main contribution of this work is the design and implementation of a learning environment that, based on AR technology, supports engineering students to complement their learning process in a complex subject with a high level of abstraction, as it is electrical circuits.

To achieve this, AR has been combined with a fuzzy logic system, to guide the student in a personalized way to solve the different exercises that are presented, superimposing information about the exercise using 3D models to represent the components of electronic circuits and thereby promote active learning.

This work is organized as follows: Section 2 presents related works on the use of augmented reality in education and fuzzy logic applied to educational environments; in section 3 the structure of the learning environment is discussed and explained; section 4 discuss the results obtained from the implementation of the application with students; and finally, section 5 offers the conclusions and future work.

## 2 Related Works

This section presents related works within AR focused on STEM learning, and works that use fuzzy logic focused on learning. In the area of AR focused on the educational field, studies are aimed at improving the motivation and spatial ability of the student.

Liao [3] designed an assistant system to solve a Rubik's cube using AR, showing clues and aids in the solution process and examining the effects in terms of student improvement, and learning concepts of volume and surface of geometric figures.

Rossano [6] designed Geo+, an application aimed to solve geometry problems in elementary school children, highlighting the ease of use, spatial skills, and the learning gain of the students.

Hruntova [7] created an application aimed at increasing the efficiency of learning based on the laws of physics applied in a laboratory, facilitating the training and cognitive activities of students and improving the quality of the acquisition of knowledge, promoting interest in a topic and the development of research skills.

Ibáñez [11] presents the acquisition of knowledge of students where the subject of electromagnetism is evaluated, comparing students who use a Web platform against students who use a mobile application using augmented reality. In this work, variables related to the students' learning flow are measured, concluding that the students who used the AR application had greater user satisfaction, but that there were aspects to improve in terms of usability in it.

Also, Ibáñez [4] presented a review of the state of the art in AR, reviewing 28 applications to promote STEM learning, classifying them, and making an analysis of the measurements they take. One conclusion is that the studies of the papers presented mainly measure affective and cognitive parameters of the students through cross-sectional experiments and that there is a need to diversify the measures to obtain a deeper understanding that goes beyond helping to remember facts and content.

On the other hand, there are also works where fuzzy logic models are implemented to evaluate different aspects of the student in learning systems. Ozdemir [8] propose to determine the effect of a mobile game on the attitude of engineering students using fuzzy logic and variations of the same model, concluding that for situations where the condition is uncertain, fuzzy logic is an effective technique.

Rathore [14] uses a fuzzy inference system to predict student placement in a school using spreadsheets and Matlab, and choosing fuzzy logic due to a large amount of data and variables involved, managing to predict and analyze large sets from students.

Gogo [15] develop a model that recommends relevant learning content to students, using a context-aware approach to obtain student-related data, and then use a fuzzy logic model to recommend learning content taken from a content database of books, tutorials, and videos, reducing the time in which a student manages to obtain learning content according to their level of mastery of a subject.

Karaci [9] proposes an intelligent tutor that uses fuzzy logic to detect errors while the students take questionnaires, creating a model that allows them to choose the following questions that will be asked in a personalized way, improving the overall performance of the students.

## 3 Structure of the Learning Environment

CircuitAR is a learning tool designed to solve Ohm's law problems, focused on learning electrical circuits in first-grade engineering students. The tool provides the student 3D elements that allow visualizing the physical form, description, and composition of the electrical circuit using batteries and resistors.

For the development of CircuitAR, a methodology for software development with an iterative and incremental approach was used [16], in which the most important requirements are developed in a first version of the software, and later versions are released to meet the other requirements, allowing to take into account the feedback of the previous versions. The learning environment is made up of a mobile application and a web application.

### 3.1 Architecture

CircuitAR is a learning tool using AR developed in Unity 2020 for Android devices, which implements Vuforia for AR, and Firebase for data persistence. As a complement, CircuitWeb was developed as a web application, that is responsible for manage all the information generated by the intervention with the students, as well as for download the markers. The platform contains 2 main clients: CircuitAR mobile application and CircuitWeb application. Both applications make requests to Google Firebase, which offers different services for the development of cloud platforms.

The services used are (1) *auth*: Registration and authentication of students. (2) *storage*: markers storage. (3) *Firestore*: Document-oriented NoSQL database. It is used for the storage of the data of the students, exercises, markers, and applied exams. Figure

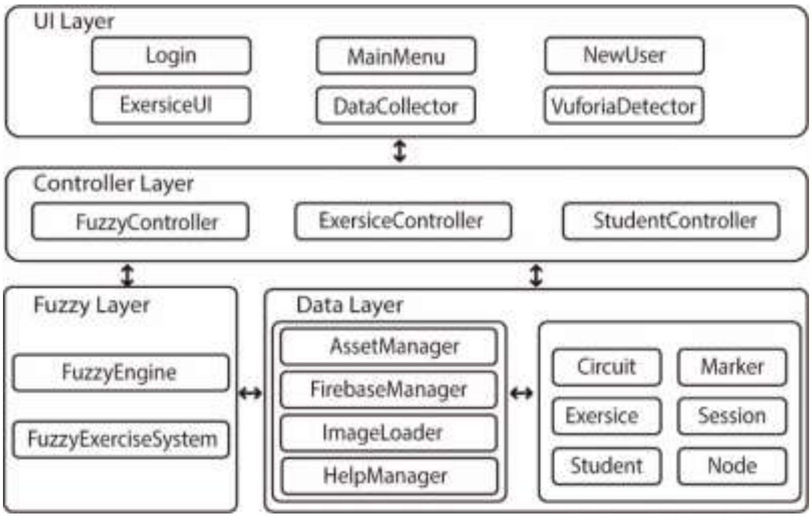


**Fig. 1.** CircuitAR architecture.


**Fig. 2.** UI interface of one of the exercises to solve.

1 shows the architecture of the CircuitAR mobile application, with its layers and components that make it up. CircuitAR components are described below.

In the ***UI layer***, there is the *ExerciseUI* component, which uses the camera of the mobile device to carry out the AR. It uses *VuforiaDetector* to interpret its image and combine reality with virtual elements for each exercise proposed by the platform. The application will show an incomplete electrical circuit, as well as graphical interface elements that serve the student as didactic support. Examples of these items are aids, instructions, the name of the exercise, and the timer.

For the students to be able to solve the exercises, the AR Engine (Vuforia) needs to recognize a marker, placing it within below the device’s camera. When Vuforia recognizes the marker, it superposes the digital elements over it and loads the possible components to complete the circuit shown.

Each marker is uniquely recognized, which allows the Unity Engine to process augmented output according to the position of the marker provided by the student [5].

Figure 2 shows the graphical interface of a CircuitAR exercise, where each number refers to the components to solve the exercise: (1) instructions for solving the exercise; (2) button to request help; (3) the title of the exercise; (4) marker required, where the element generated by the markers should be positioned; (5) markers available for possible response to the exercise; and (6) the timer to solve the current exercise.

The *Controller layer* contains components that receive requests from the *UI layer*, either requesting or sending information. Its function is to coordinate and organize the logic of the application. This applies to each of the application modules, these being: student (*StudentController*), exercises (*ExerciseController*), and the fuzzy logic (*FuzzyController*). The *UI layer* manages the user's graphical interfaces through which the student registers and authenticates in the system. *ExerciseUI* is the component with which the student performs the exercises. It relies on *VuforiaDetector* to be able to carry out AR and on *DataCollector* to obtain information about how the student is performing during the exercises.

The *Data layer* contains components that perform communication tasks with Firebase through *FirebaseManager*, whose function is to manage, store and obtain the data necessary for the student to complete the exercises. *ImageLoader* gets the files hosted on that platform. *HelpManager* stores and suggest the clues to solve a problem. All this interaction will occur through objects of the domain component. Within the fuzzy component, *FuzzyExerciseSystem* and *FuzzyEngine* are in charge of taking the student's performance data and applying the rules of the fuzzy model. The *Fuzzy Layer* is described below.

### 3.2 Fuzzy Logic Model

The *Fuzzy layer* is responsible to adapt the content of an exercise to be solved according to the student's performance, a fuzzy logic model was implemented that evaluates the level of complexity of the following exercise based on the linguistic variables that correspond to the number of errors made by the student, the aids requested, and the time necessary to solve the exercise per shift. The *FuzzyController* subcomponent selects the exercises that students should perform, based on the recommendations made by the fuzzy inference machine, and provides relevant feedback to the student.

The fuzzy inference machine adapts the pedagogical model according to the student's performance, considering the input variables, fuzzy sets, and defined labels. The result of the inference is a fuzzy output variable called "nextLevel", which represents the level of difficulty applicable to the next exercise with fuzzy values of *beginner*, *easy*, *medium*, and *hard*. Once the linguistic variables are defined, the fuzzy system applies the fuzzy rules for each set of values of the 3 input variables. Each fuzzy variable is normalized in a range between 0 and 1. Since there are 4 input variables, 3 of them with 3 possible values and one with 4, 81 rules have been defined, each giving a corresponding value to the output variable. An example of a fuzzy rule is:

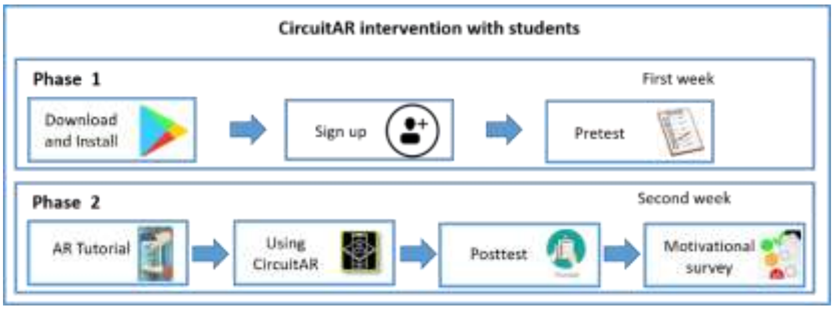


**Fig. 3.** Steps of the intervention with the learning tool.

*IF prevLevel IS beginner AND errors IS None AND helps IS low AND time IS fast THEN nextLevel IS easy*.

## 4 The Experiment, Evaluation, and Results

To evaluate the effectiveness of CircuitAR, two aspects were considered: the functionality of the platform and the intervention with students from the second semester of the electronic engineering career, from the Technological Institute of Mazatlán, in a distance mode. Our proposal was adapted to the COVID-19 pandemic's needs, and we implemented the intervention using a distance learning tool and an online platform. The following adjustments were made: (1) markers for AR were available on CircuitWeb, either for printing or viewing from the web; (2) the application was available for download in Android Google Play[1], avoiding distribution and permission problems in the equipment, as well as increasing the confidence of the students by being in an environment known to them; (3) pretest and posttest questionnaires are also available on CircuitWeb platform.

These actions allowed better control of the experiment, thus achieving that the sessions with the students could be carried out remotely. Similarly, because the pretest and posttest were accessible through the web platform, students were more motivated to complete them because they didn't have to leave the application to answer them. Regarding the functionality of the platform, feedback was received from the students during the sessions using the tool. For this, observations were collected that allowed us to improve the learning environment for future iterations of development.

The intervention was designed in 2 phases: In the first phase, the students download and install the application. Once installed, the student proceeds to sign up. When the student signs in, the pretest option is enabled to respond the questionnaire for 15 minutes. Phase 2 begins with a video tutorial about the use of AR, as well as an example of how to use the marker collision technique, lasting 10 minutes. Subsequently, instructions are provided on how to interact with CircuitAR, and for 20 minutes, students must solve the exercises proposed in the application.

[1] https://play.google.com/store/apps/details?id=com.mcc.circuitar

**Table 1.** Data analysis from pretest and posttest.

| | | Pretest | | | Posttest | | | |
|---|---|---|---|---|---|---|---|---|
| School | **N** | **Pass** | **Fail** | **M** | **Pass** | **Fail** | **M** | **t** |
| **School 1** | 30 | 14 | 16 | 5.40 | 18 | 12 | 6.23 | -3.192 * |
| **School 2** | 28 | 12 | 16 | 5.42 | 18 | 10 | 6.28 | |

* p-value < 0.05

During that time, the research team attends and solves student difficulties with the handling of the application.

Once the interaction is finished, the student must answer a posttest questionnaire for 15 minutes, with the same degree of complexity as the pretest.To end the session, the student must answer a motivational survey, made up of 36 questions with 5 possible answers in 20 minutes. Figure 3 shows the steps of the intervention with CircuitAR.

During the intervention with CircuitAR, 58 students from two different schools were evaluated. According to the data obtained from the pretest from School 1 (N=30, M=5.40, SD=2.30), 14 students obtained a score higher than 6.0 and 16 students obtained a score lower than 6.0. Regarding to the data obtained from School 2 (N=28, M=5.42, SD=2.36), 12 students obtained a score higher than 6.0 and 16 students obtained a score lower than 6.0. Similarly, the data obtained from the post-test were analyzed. The students of School 1 (M=6.23 SD=2.21), 18 obtained a score higher than 6.0 and 12 students obtained a score lower than 6.0.

Regarding School 2 (M=6.28 SD=2.29), 18 students obtained a score higher than 6.0 and 10 students obtained a score lower than 6.0. Table 1 shows the results of pretest and posttest from both schools. A paired sample T-test was conducted to the data, grouping both schools to compare the learning outcomes of the students based on the data from the pretest and posttest. The result indicated that there was a difference statistically significant between the students' knowledge before the intervention and after using CircuitAR, t (58) = -3.192, $p$=0.002, it can be established that the students had improved the learning outcome by using the AR learning tool.

## 5 Conclusions

CircuitAR is a learning tool that guides students to learn electronic circuits using AR effectively. With The fuzzy logic model designed and implemented to be able to choose which exercises to show the student based on their previous performance, it is effective to have a greater learning gain. The information generated by the students' intervention carried out, and the data of pretest and posttest questionnaires reflect that the students gained a significant learning outcome compared to before interacting with the application, demonstrating that the combination of augmented reality to improve the learning experience of electrical circuits.

On the other hand, students expressed felt identified with the elements provided by the application, arguing that the learning tool is unique and effective for learning, in addition to having provided feedback on the usability and performance of the application on different devices, indirectly collaborating to detect and propose possible solutions to display and performance problems within CircuitAR.

This study had a limited sample size, due to the distance modality and because of the time in which the intervention was carried out.

For this reason, the size of the sample should be increased and other interventions with students should be carried out to analyze the impact of the tool in different contexts. As future work, it is planned to expand the didactic proposal of the platform, increasing the number of available exercises, and the variety of electrical elements that students use to improve their learning. Also, integrating new types of exercises apart from the one proposed in this work, and, integrating a greater degree of feedback during the intervention with augmented reality exercises, through sound effects and animations.

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