Pedagogical Support Tools: Integrating Digital Tools for Learning about AC Electrical Circuits within Electronic Engineering

Herramientas de apoyo pedagógico: integración de herramientas digitales para el aprendizaje en circuitos eléctricos de corriente alterna en la ingeniería electrónica

Ferramentas de apoio pedagógico: integração de ferramentas digitais para aprendizagem em circuitos elétricos de corrente alternada em engenharia eletrônica

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Received: January 15th, 2024
Accepted: April 10th, 2024
Available: May 7th, 2024

How to cite this article:
L.R. Achicanoy, F.A. Dulce Mer, "Pedagogical Support Tools: Integrating Digital Tools for Learning about AC Electrical Circuits within Electronic Engineering," *Revista Ingeniería Solidaria,* vol. 20, no. 2, 2024.
doi: https://doi.org/10.16925/2357-6014.2024.02.05

Research article. https://doi.org/10.16925/2357-6014.2024.02.05

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Abstract

Introduction: This article is a product of the scientific research "Analysis of the impact of including interactive platforms oriented to electronic engineering education" developed at CESMAG-Colombia University and the university corporation AUNAR-Colombia between 2021 and 2023.

Problem: What is the impact on student learning with the inclusion of digital tools (virtual reality, augmented reality, and multimedia) for support in the alternating current (AC) academic space in electronic engineering?

Objective: To analyze the impact on student learning by including digital tools (virtual reality, augmented reality, and multimedia) to support the alternating current (AC) academic space in electronic engineering.

Results: The research results indicate a significant increase in the student's motivations when using support tools, especially the development of augmented reality (AR), which had a great reception, and the students who used this tool obtained the best grades in evaluating the selected topic.

Conclusions: As demonstrated throughout the development of this project, these digital tools can significantly support understanding topics that are difficult to visualize within a classroom, thus achieving improved motivation through the tests performed and evidencing that the methodology with AR and virtual reality (VR) had a better reception.

Originality: This work compares the three technologies, VR, AR, and multimedia, allowing us to establish their advantages in their application in university education.

Limitation: This research was developed specifically with the inclusion of digital tools with CA circuit students at CESMAG University, so it does not deal with other types of students going to review Lenz's Law.

Keywords: Learning, Virtual Reality, Augmented Reality, Multimedia, Technology.

Resumen

Introducción: Este artículo es producto de la investigación científica "Análisis del impacto de la inclusión de plataformas interactivas orientadas a la educación en ingeniería electrónica" desarrollada en la Universidad CESMAG-Colombia y en la corporación universitaria AUNAR-Colombia entre 2021 y 2023

Problema: Cuál es el impacto en el aprendizaje de los estudiantes con la inclusión de herramientas digitales (realidad virtual, realidad aumentada y multimedia) para el apoyo en el espacio académico de corriente alterna (CA) en ingeniería electrónica

Objetivo: Analizar el impacto en el aprendizaje de los estudiantes con la inclusión de herramientas digitales (realidad virtual, realidad aumentada y multimedia) para el apoyo en el espacio académico de corriente alterna (CA) en ingeniería electrónica.

Resultados: Por los resultados de la investigación señalan que hay un gran aumento en la motivación de los estudiantes al utilizar herramientas de apoyo, especialmente el desarrollo de RA tuvo una gran recepción y los estudiantes que utilizaron esta herramienta lograron obtener las mejores calificaciones en la evaluación del tema seleccionado.

Conclusiones: Como se demuestra lo largo del desarrollo de este proyecto estas herramientas digitales pueden llegar a ser un gran apoyo en la comprensión de las temáticas que son difíciles de visualizar dentro de un aula de clase, logrando así mejorar la motivación a través de las pruebas realizadas y evidenciando que la metodología con RA y RV tuvieron una mejor acogida.

Originalidad: Se destaca que este trabajo hace un aporte en la comparación de las 3 tecnologías, VR, AR y multimedia, permitiendo establecer qué ventajas tienen en su aplicación en la educación universitaria

Limitación: Esta investigación se desarrolló específicamente con la inclusión de herramientas digitales con los estudiantes de circuitos de CA en la Universidad CESMAG por lo que no trata con otro tipo de estudiantes vayan a revisar la Ley de Lenz.

Palabras clave: Aprendizaje, Realidad Virtual, Realidad Aumentada, Multimedia, Tecnología.

Resumo

Introdução: Este artigo é produto da pesquisa científica "Análise do impacto da inclusão de plataformas interativas voltadas à educação em engenharia eletrônica" desenvolvida na Universidade CESMAG-Colômbia e na corporação universitária AUNAR-Colômbia entre 2021 e 2023.

Problema: Qual o impacto na aprendizagem dos alunos com a inclusão de ferramentas digitais (realidade virtual, realidade aumentada e multimédia) para apoio no espaço académico de corrente alternada (CA) em engenharia eletrónica?

Objetivo: Analisar o impacto na aprendizagem dos alunos com a inclusão de ferramentas digitais (realidade virtual, realidade aumentada e multimídia) para apoio no espaço acadêmico de corrente alternada (CA) em engenharia eletrônica.

Resultados: Os resultados da pesquisa indicam que há um grande aumento na motivação dos alunos ao utilizar ferramentas de apoio, principalmente o desenvolvimento da RA teve uma ótima recepção e os alunos que utilizaram esta ferramenta conseguiram obter as melhores notas na avaliação dos selecionados. tópico.

Conclusões: Conforme demonstrado ao longo do desenvolvimento deste projeto, estas ferramentas digitais podem ser um grande apoio na compreensão dos temas de difícil visualização dentro de uma sala de aula, melhorando assim a motivação através dos testes realizados e mostrando que a metodologia com AR e VR foi eficaz. melhor recebido.

Originalidade: Destaca-se que este trabalho contribui na comparação das 3 tecnologias, VR, AR e multimédia, permitindo-nos estabelecer quais as vantagens que apresentam na sua aplicação no ensino universitário.

Limitação: Esta pesquisa foi desenvolvida especificamente com a inclusão de ferramentas digitais com alunos de circuitos AC da Universidade CESMAG, portanto não trata de outros tipos de alunos que irão revisar a Lei de Lenz.

Palavras-chave: Aprendizagem, Realidade Virtual, Realidade Aumentada, Multimídia, Tecnologia.

1. INTRODUCTION

The learning of alternating current (AC) electrical circuits is a fundamental part of the formation of an engineer since it is a primary subject in the learning of the topics for the courses of higher-tier semesters; more precisely, the courses of circuits and physics. As this course is not exclusively for people who are studying engineering, it is a subject that can even be developed in schools, in which the need arises to strengthen the concept of electrical circuits as indicated by the authors Mendoza, Parra and Rúa [1]. Although this subject is not easy to cover, it can be made more dynamic and easier to understand. A solution would be restructuring the chronogram, which would

generate a new restructuring of the system as it is known and can even make an extension into the career.

Virtual reality (VR), augmented reality (AR), and multimedia develop a more comprehensive class. VR defines a reality or parallel world in which users can see or interact with it; augmented reality is a type of technology in which virtual content can be used in the physical world, according to Bockholt [2]. They have been and will be innovative technologies from which you can acquire a lot of advantages in many areas and topics, facilitating the development of material that can be used in a class; for example, they can be used to develop a series of videos in which the subject matter is even easier to understand and where interaction with virtual objects is possible. This makes virtual reality and augmented reality excellent options where both the teacher and the student can be supported and increases learning motivation.

As demonstrated in the development of this project, several investigations that are also used as references (since they have a similar development to the present project) have had good results. An example of this is the undergraduate work project developed by Bologna and Garcia [3], which had 82% satisfaction with the tool developed to train industrial engineering students, achieving an improvement of 55% in the time used for the training. Horváth's paper suggests the utilization of existing new digital tools; [4] this paper is about the application of new digital tools to help, more specifically, teachers and lecturers, showing that user operations were reduced by 40%.

In accordance with the above, it follows that this degree project aims to include different digital tools (Virtual Reality, Augmented Reality, and multimedia) in the academic space of alternating current circuits in order to analyze if they result in efficient pedagogical support in the sense that it motivates students in their academic process. The methodology considered for the development was the application of surveys to a professor and students of the alternating current circuits course, selection of the target topic, development of the experiment in virtual reality, augmented reality and multimedia, testing of the experiment developed with third-semester students who study alternating current circuits and finally, the evaluation of the results. These results show that there is a significant increase in the motivation of the students when using the tools as support; in particular, the methodology with Augmented Reality had a good reception, and the students who used the tool managed to obtain the best grades in the evaluation of the selected topic.

1.1. Literature review or research background

In the paper by Palencia and Vivas [5], it is evident that alternatives, such as simulators, have been used to educate engineering students, more precisely, for agricultural engineering; although the subject to be dealt with is purely electrical circuits, there is a lack of knowledge of the usefulness of the elements that compose it. The collection technique used for the research was the survey, and the instrument was a questionnaire consisting of 13 questions with dichotomous answer options. The Kuder-Richardson method allowed for validation that the used instrument gave a result of 0.81.

The paper by Radianti, Majchrzak, Fromm, and Wohlgenannt [6] concerned higher education with immersive virtual reality. It found that 24% of engineering courses used immersive virtual reality to support education and that questionnaires are the most common method of evaluation of learning outcomes with 22%. Also, the elements of immersive virtual reality design and the integration of said systems were analysed.

This illustrates a significant interest in the adoption of technologies like immersive virtual reality in higher education. Furthermore, it is noteworthy that numerous articles across various research fields have explored projects utilizing virtual reality as an education tool. Additionally, among these articles, 17 specifically focus on the research aimed at enhancing practical and procedural knowledge.

The paper by Nur Idawati Md Enzai, Norhayati Ahmad, Mohd Amir Hamzah Ab. Ghani, Siti Rais, Syazilawati Mohamed, and Nur Idawati Md Enzai [7] was developed with an emphasis on the low resources in laboratories and the current pandemic, centralized to help engineering with the help of augmented reality tools because it has a facility of a medium in which it can be visualized, such as phones and tablets. Also, the help of augmented reality generates interest and motivation for the students.

For this research, the application used to develop a system was "Assemblr", where you can identify and understand the functions of the components within a motherboard; the research focuses on the development of the application after a survey of professors stated that virtual reality is well received and has great potential to involve students in this new process of teaching and learning.

The paper by Piedad Metaute, Giovanny Flórez, Paul Rúgeles, and Diego Castaño [8], which provides a series of elements to create a pedagogical strategy for the Faculty of Basic Sciences and Engineering of the Corporación Universitaria Remington, states that the appropriate tool should facilitate the development of the class in alignment with the required competencies.

The strategies used in the article were the masterclass, academic discussion, constructivism, business visits, and laboratories. Both students and teachers

answered the survey, from which it is possible to affirm that the least used strategy, with 0%, is business visits, and the least used support tool is virtual platforms, with 9%. The least used evaluation strategies are exposure with 9% and fieldwork with 6.5%, with the results of the research used to help design, construct, and implement of a new pedagogical strategy that is consistent with the needs of society.

Sergio Zabala, John Pérez, and Henry Rodríguez [9] developed a pilot experience to integrate Information and Communication Technologies (ICT) with competitive robotics in the article. This project took place in both public and private schools in the city of Bucaramanga, as well as among students at the UDI (Industrial University of Santander) pursuing a degree in electronic engineering. The authors highlight the implementation of new pedagogical strategies, not only at the university but also in schools, where robotics serves as a stimulus for developing skills in modeling, design, and product implementation. In the university context, the project unfolds as a process involving the analysis of the challenge, the creation of a mechanical design for the device, an electronic stage, and the development of a prototype.

The article by Daniel Sampaio Pedro Almeida [10] considers some pedagogical strategies for the inclusion of AR in teaching with ICT and learning processes, the inclusion of new technologies in an educational environment, which opens the possibilities for teachers to develop innovative classes in teaching methods and invent new situations in which the student can expand their skills.

An article by John Kirby, Phillip Moore, and Neville Schofield [11] concerns three studies where a questionnaire was developed that evaluates verbal and visual learning styles. The paper postulates the existence of students who may have greater engagement with some of these styles and the ability to switch between verbal and visual depending on the subject or the skills to be acquired.

The paper by Chris Fowler [12] identifies the learning benefits derived from 3D virtual environments, including pedagogical requirements, which must be part of the learning experience design, where the idea of immersion is the critical concept that can mediate between technology and pedagogy.

The paper developed by Jose Wolfartsberger [13] analyzes the potential of VR in an engineering design review. VR can provide a realistic and safe experience for users in an environment that is complicated to recreate in the real world; in Industry 4.0, one of the main focuses was coupling the digital and virtual world with the real world, a cyber-physical system.

The paper written by Franck Luthon and Benoit Larroque [14] proposes a virtual learning management system oriented to e-learning applications covering the whole process; for e-labs to be exciting/stimulating, the users must have access through

the web and its implementation must be simple. It is also proposed that the benefit of a remote lab should be evaluated and compared with simulation or practice labs.

A paper by Yong-Ho Yoo and Wilhelm Bruns [15] whereat they worked with Virtual equivalences, a concept used for the implementation of bidirectional interfaces based on energy bridging between real and virtual models, presents the concept of a continuous flow of electrical energy (Current * Voltage); its theoretical foundations and implementation are via a bidirectional mixed reality port.

The paper by Burkodi, Kiss, Karkus, Varga, and Vajk [16] developed a 3D remote laboratory that allows a large number of users to learn about the mathematical modeling of dynamic systems and test control algorithms on a virtual platform. It aims to give users a realistic virtual experience of real devices and has the flexibility to perform experiments at any time, no matter the place and time, as long as they have internet connectivity.

Other virtual laboratory projects focusing on control include Dormido et al. [17]. Here a virtual laboratory was developed that is Web-based for experimentation in nonlinear multiple-input multiple-output (MIMO) systems, developed in Easy Java Simulations (EJS), which is a tool for users with little programming experience. Also, Saenz et al. in [18] developed a laboratory for the application of a control system in a virtual environment, which can be commanded remotely only with an internet connection; this system allows for the implementation of controllers with two inputs and two outputs in industrial applications. Additionally, this laboratory was coupled to a web learning system to facilitate its management and maintenance.

2. MATERIALS AND METHODS

It is necessary to use surveys to determine the subject on which the project is to be developed; this survey should be applied both to the teacher in charge of the academic space and to the 3rd-semester students who take the academic space of AC electrical circuits. Finally, the results are evaluated, and the learning percentage was determined.

For the development of the resources with Unity for VR, we used version 2021.3.18f1 with the package "Oculus Integration" version 56.0 for the interactive part of the menu scene, and the package "XR Interaction Toolkit" version 2.2.0 for the interactive part of the experiment scene. For AR version 10.15.4 of Vuforia in Unity was used. In regards to development, for the multimedia tool, Renderforest was used, which is a platform for creating videos and animations. Finally, for multimedia, we

developed a video that answers the following questions in the same order: What is it? What is it for? How does it work?

The Fig. 1 summarizes the above.

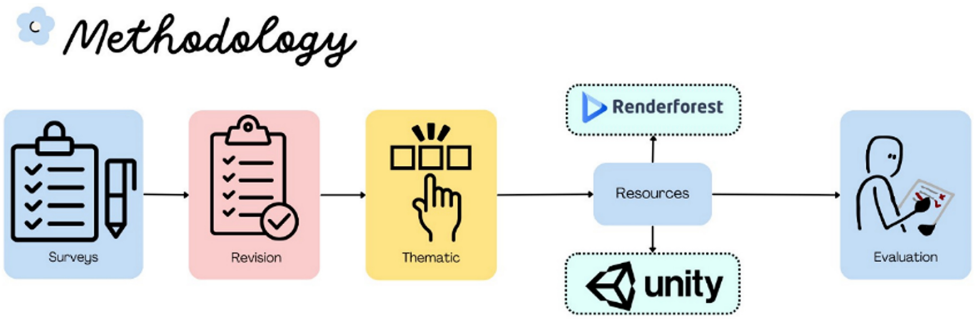

Fig. 1 Methodology
Source: Own work

2.1. Description of the problem

Generally, developing a subject involves conducting a masterclass with student-teacher interaction. Both the teacher and the students need prior knowledge for the class development. They undertake the task of consulting the subject to be addressed and unifying the identified concepts. Typically, this strategy is employed at the beginning of a new subject. Additionally, workshops serve as a strategy to verify the concepts previously studied in masterclasses and consultations through practical application. The evaluation criteria encompass written tests, problems, presentations, challenges, and observation guides. Evaluation is carried out through performance analysis, teamwork, and observation of the teaching and learning environments [19].

The micro curriculum of the university supports the information mentioned above. However, this trend is not exclusive to CESMAG University (Colombia); it is also evident in other institutions such as the Universidad Veracruzana (Ecuador) [20]. The Universidad Veracruzana conducted a course workshop on alternating current circuits, revealing a strategy remarkably similar to the one employed in the micro curriculum of CESMAG University. Additionally, research on the dynamization of strategies in engineering classes [8] indicates that pedagogical strategies such as masterclasses, constructivist strategy, laboratory strategies, project strategy, and academic discussions are the most frequently used in teaching engineers at the Lasallian University corporation. The same paper recommends adapting these strategies to the needs of 21st-century students.

Within the course on alternating current circuits, topics center on the analysis of idealized circuits, the methods for conducting such analyses, and the frequently used passive filter topics, which may induce several doubts due to their complexity. To address this challenge, educators should propose new strategies to enhance the teaching of the alternating current course, supplementing those already suggested in the micro curriculum. These additional strategies strive to enhance the dynamism of the class.

In various instances, educators have observed positive outcomes regarding the use of digital tools as supportive strategies, such as the case of the undergraduate project at the University of Ambato [3]. Industrial engineering students in this program experienced a 55% reduction in training time. Similarly, an article on the tasks and functions of teachers involving virtual reality and augmented reality [4] reported a 72% reduction in machine operations and a 40% decrease in user operations. Based on these results, it can be concluded that digital tools significantly support both students and teachers. Consequently, the impact of digital tools on the course of alternating current electrical circuits at CESMAG University is of interest and warrants further exploration.

2.2. Justification of the research project

Education evolution involves the integration of digital tools and new technologies for learning, as these innovative forms of support center on understanding a subject or course. In this project, a diverse course covering topics related to alternating current and essential components such as capacitors and inductors is addressed. It also extensively explores passive filters, commonly used in subsequent courses. Approaching learning from a different perspective could lead to improvement. The digital tools to be applied have already gained widespread use in education, as evident from their background, making them suitable for this work.

According to Radianti, Majchrzak, Fromm, and Wohlgenannt [6], immersive applications in virtual reality most commonly teach practical procedural knowledge. The engineering field has seen numerous articles developed on the use of immersive virtual reality, indicating that it is a viable and grounded approach to teaching concepts, activities, and skills.

This project, creating interaction between the virtual world and reality, establishes a more accessible and engaging environment, facilitating a better understanding of challenging subjects. Virtual reality and augmented reality not only assist students but

also provide support to teachers, who need to understand how virtual reality works and determine the interface that will enhance student comprehension [6].

When executed, this project will lead to a noticeable improvement in understanding essential topics crucial for future subjects. The goal of this project is to inaugurate a new form of teacher-student interaction in electronic engineering at CESMAG University, providing a simple and dynamic approach to subject development.

3. RESULTS

3.1. Application of surveys (students and teachers)

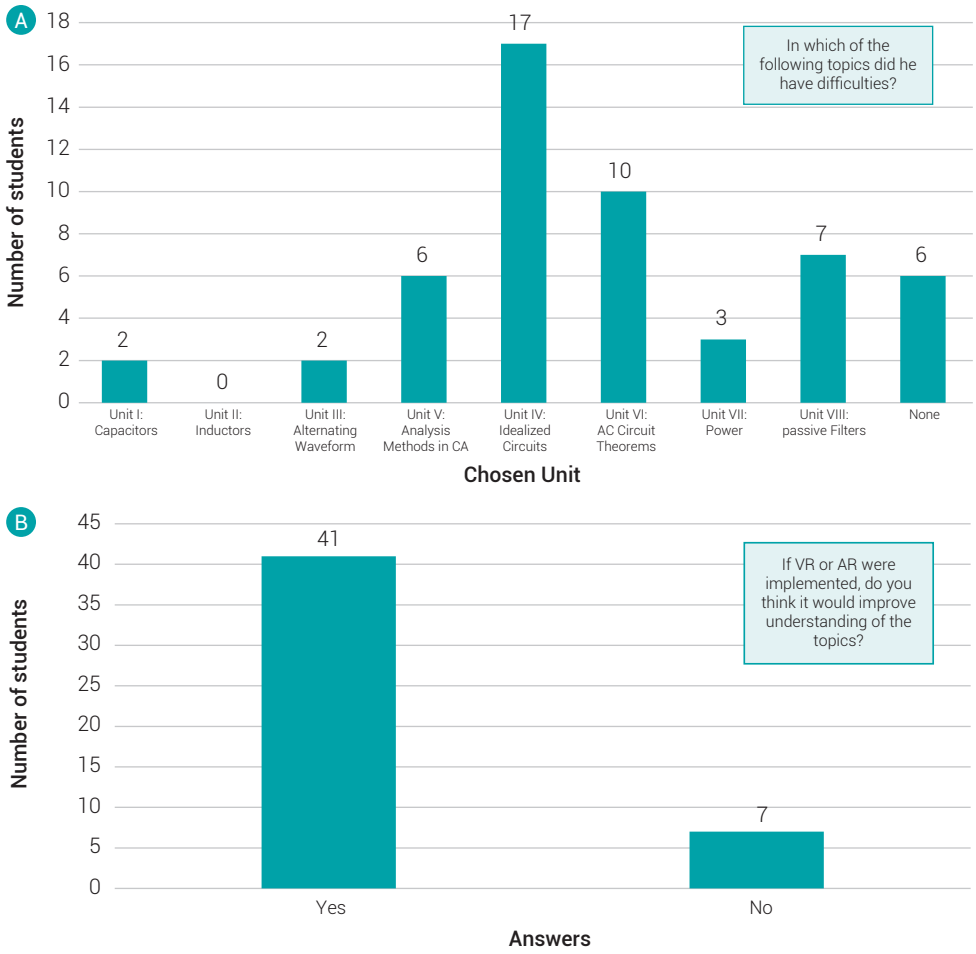

Fig. 2 A) Question on the difficulty of the topics B) Question on the improvement of understanding of the topics if VR and AR are implemented.
Source: Own work

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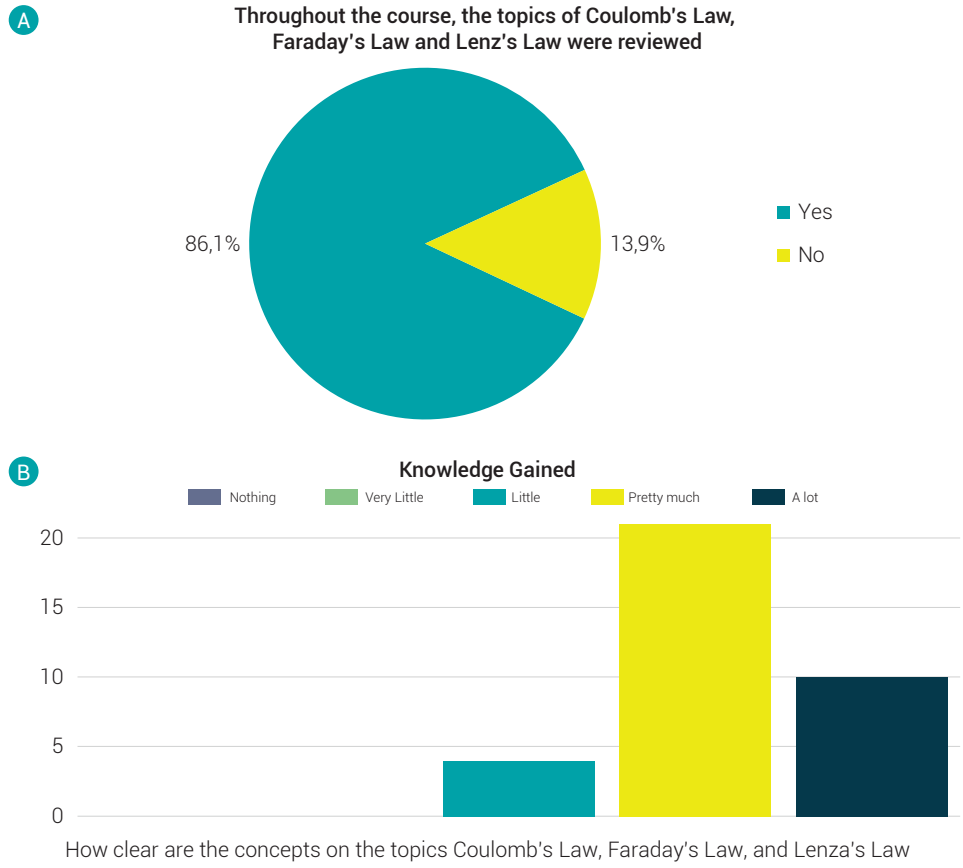

Fig. 3 A) Question on topic review B) Question on clarity of topics
Source: Own work

Surveys have been applied to students of period 2 (August - December) of 2021 and period 1 (February - June) of 2022. Four questions stand out which can be seen in Fig. 2 and Fig. 3 However, a synthesis of the most relevant statistics of the graphs is shown in Table 1.

Table 1. Percentage responses to salient questions in student surveys

Questions	Responses (%)
In which subjects do they have difficulty	35.42% have difficulty in unit V on methods of analysis in CA.
If VR and AR were implemented, do you think it would improve the understanding of the topics?	85.42% answered that Yes would improve understanding.
Coulomb's Law, Faraday's Law and Lenz's Law were reviewed throughout the course.	13.9% answered that they did not review the topics.
How clear are the concepts on the topics Coulomb's Law, Faraday's Law and Lenz's Law?	16.67% answered that the concepts were unclear.

The teacher in charge of the subject of electrical circuits of alternating current was questioned, highlighting two questions with their responses:

"What topics usually receive the lowest grades from students?"

The response indicated that, generally, two crucial topics attract the lowest grades. During the initial assessment period, topics such as electric field, magnetic field, and their application in the design and construction of capacitors and inductors are covered. This period also involves defining equations and waveforms for the transient and discharge stages of these elements. The second topic with lower grades arises in the second assessment period when working with RL, RC, and RLC circuits. Students often find it challenging to comprehend the phase shifts of the waves occurring in these circuits.

"If you could use virtual reality or augmented reality, with which subject would you use it?"

The response was that the teacher believes virtual reality or augmented reality is a tool of the present and future in teaching. The teacher would certainly use it in several subjects of this course, such as understanding the behavior, creation, and operation of electric and magnetic fields. The teacher would even consider employing it for a visual explanation of some laws, such as Faraday, Lenz, or Coulomb.

Based on the surveys conducted with both students and the teacher in charge of the subject of alternating current circuits (as detailed above), the topic selected for further exploration is Lenz's law.

3.2. Development of digital tools

An experiment related to Lenz's law is developed and explained using various digital tools, as shown in Fig. 4.. Fig. 4 Scene A, displayed in the glasses upon opening the application, features two buttons: "Experiment" directing to Fig. 4 C, and the button "About the experiment" opening Scene B. In Fig. 4 B, we provide a brief textual and visual overview of the experiment. Fig. 4 C showcases the objects involved in the experiment, including the galvanometer connected to supports holding a coil through which a neodymium magnet will pass. The design of the hands is also visible. Additionally, Fig. 4 C displays a close-up shot detailing the checklist that can activate or deactivate the field lines in the magnet and the coil (Fig. 4 D).

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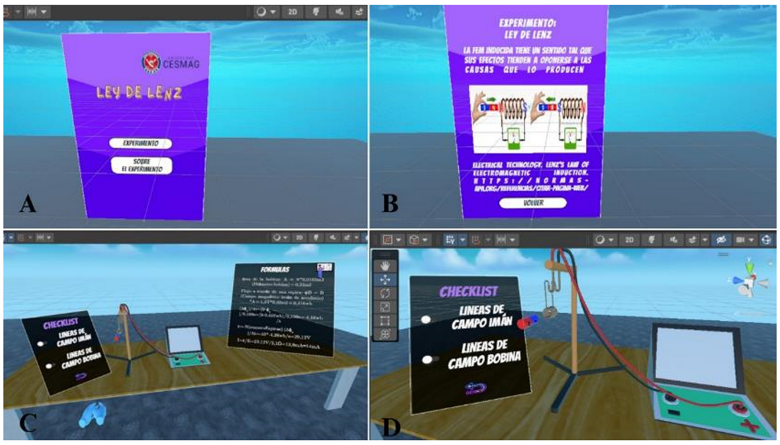

Fig. 4 A) Main menu in VR with the help of unity B) Inside the experiment button C) Lenz's law experiment scene D) Lenz's law experiment elements

Source: Own work

In Fig. 5, the development of AR can be observed. Fig. 5 A depicts the scene displayed upon opening the application, featuring two buttons. The first button, labeled "Experiment," guides the user to Fig. 5 C, and the button "About the experiment" opens the scene shown in Fig. 5 B. In Fig. 5 B, a brief textual and visual review is provided of the experiment to be conducted. Fig. 5 C showcases the objects utilized in the experiment, such as the galvanometer connected to supports holding a coil through which a neodymium magnet will pass. It also illustrates how it works and specifies the image target, additionally shown in Fig. 5 C. Moreover, in Fig. 5 D, a close-up shot detailing the checklist was captured, used to activate or deactivate the field lines in the magnet and the coil, along with controls for moving the magnet.

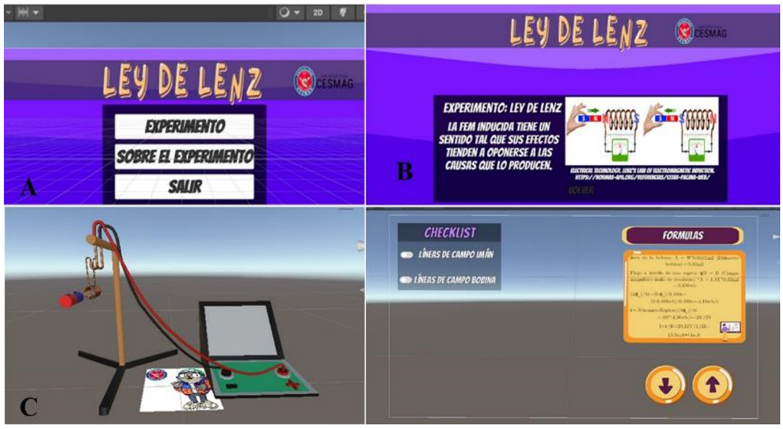

Fig. 5 A) Main menu in AR with the help of Unity B) Inside the button on the experiment C) Lenz's law experiment with Image Target D) AR controls

Source: Own work

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In Fig. 6, multimedia was utilized to develop a video with the assistance of a template on the Renderforest website, as its model closely resembles PowerPoint. Each slide within this presentation already incorporates an animation, resulting in a dynamic video. This video serves the same purpose as the other tools, namely, illustrating Lenz's law through the experiment.

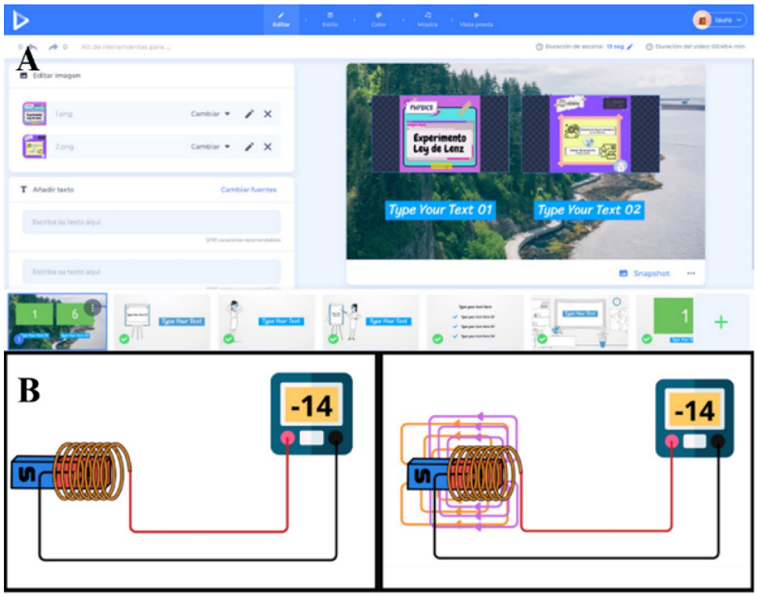

Fig. 6 A) Multimedia development in Renderforest B) Fraction of multimedia development
Source: Own work

3.3. Testing methodology

The methodology for conducting the final test involved selecting a group of students and dividing them into four subgroups, with each subgroup being exposed to different teaching tools. Group 1 served as a control and received traditional classes with the teacher, while Group 2 utilized virtual reality (VR), Group 3 utilized mobile devices for augmented reality (AR), and Group 4 utilized multimedia, watching a video on YouTube. Each group underwent a diagnostic assessment based on questions from Lenz's Law theory, and satisfaction surveys were administered to Groups 2, 3, and 4. The results of the diagnostic assessments were evaluted, assigning a value of 5.0 to correct answers and 0.0 to incorrect answers. The groups were compared in terms of the number of students who obtained a grade higher than 3.0 (the passing grade in Electronic Engineering) and their averages, thereby determining which tool facilitated more significant learning.

3.4. Test development

A user manual has been developed as a guide for both virtual reality and augmented reality, explaining the experiment and the associated elements. Additionally, at the end of the practice, we will conduct a test-type assessment, requiring participants to answer five questions related to Lenz's Law.

Furthermore, we conducted a pilot test with 14 students in the 3rd semester of the first period of 2023 who were studying electrical circuits of alternating current. This test specifically employed virtual reality. It was observed that during the test, 78% of the participants answered all five questions correctly.

Table 2. Percentage responses to satisfaction survey questions.

Questions	Responses (%)
How would you describe the new teaching methodologies?	94.1% of the students would describe these new teaching methodologies as suitable and highly suitable, which implies that they not only meet expectations but also represent a significant contribution to education. These new methodologies thus become a valuable tool in the sense that they motivate students in the learning process.
Do you consider that this teaching methodology provides an important contribution to the Electronic Engineering program and to Cesmag University?	94.1% of the students consider that the new methodologies provide a significant contribution to the program and the university. This high percentage indicates the importance of continuing to implement and improve these new methodologies in the Electronic Engineering program and at CESMAG University, as a positive impact on the perception of the new methodologies in students is observed.
What is the level of understanding of the topic you wanted to communicate (where 1 is not at all understandable and 5 is very understandable)?	82.3% suggests that the level of understanding of the topic ranges between understandable and highly understandable, so it is deduced that the methodologies successfully address the comprehension of the content in the different methodologies, facilitating the learning process.

The information presented in Table 2 provides a more detailed view in Fig. 7. Finally, the 26 students were divided into four groups for the final test: 9 students experienced the traditional method, 6 students used VR, 5 students utilized AR, and 6 students engaged with multimedia. The results of the various tested methodologies are depicted in Fig. 7, and further, in Fig. 8.

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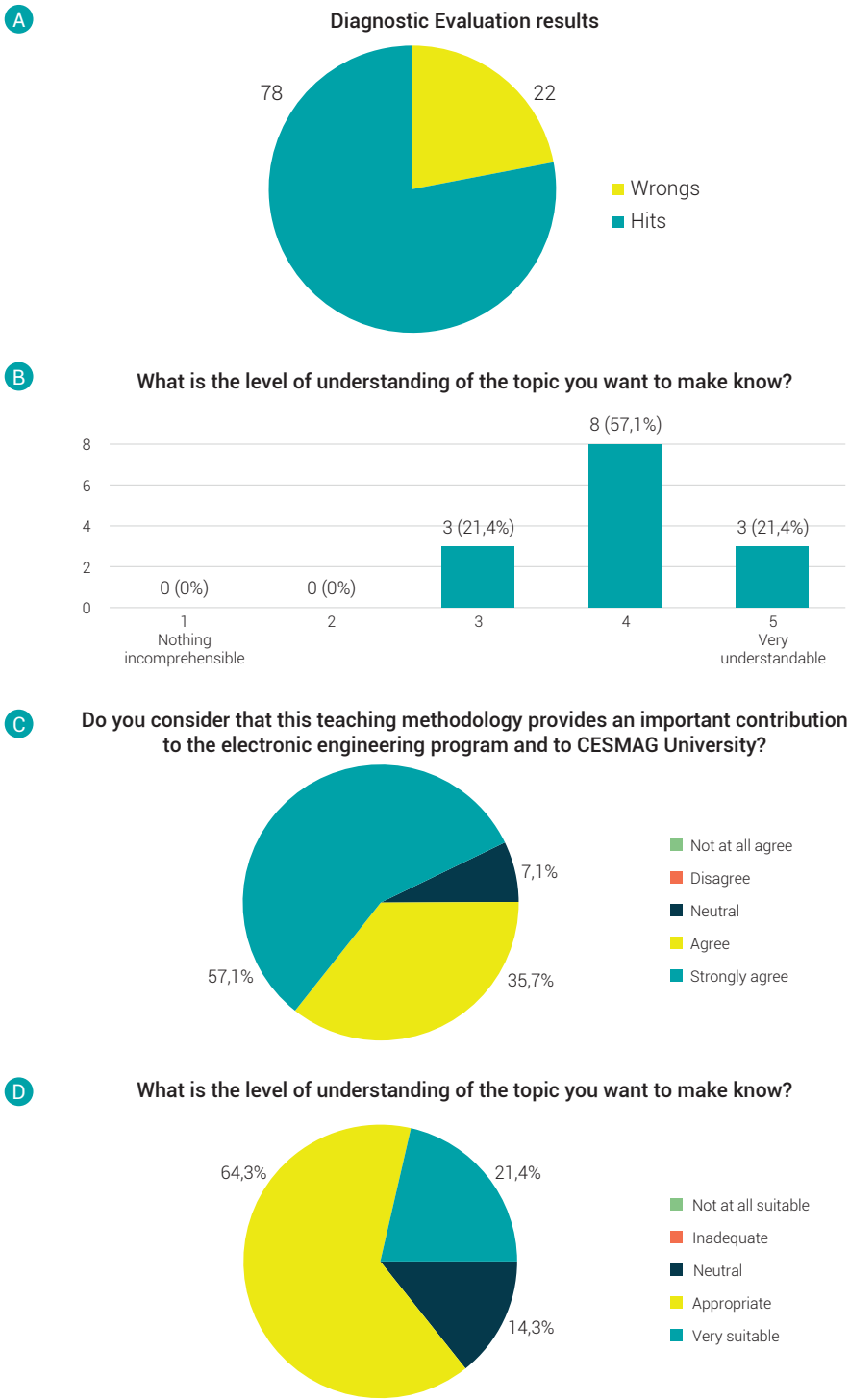

Fig. 7 A) Results of the diagnostic evaluation of the pilot test B) Level of understanding of the subject C) The teaching methodology is an important contribution to the Electronic Engineering program D) Description of new teaching methodologies

Source: Own work

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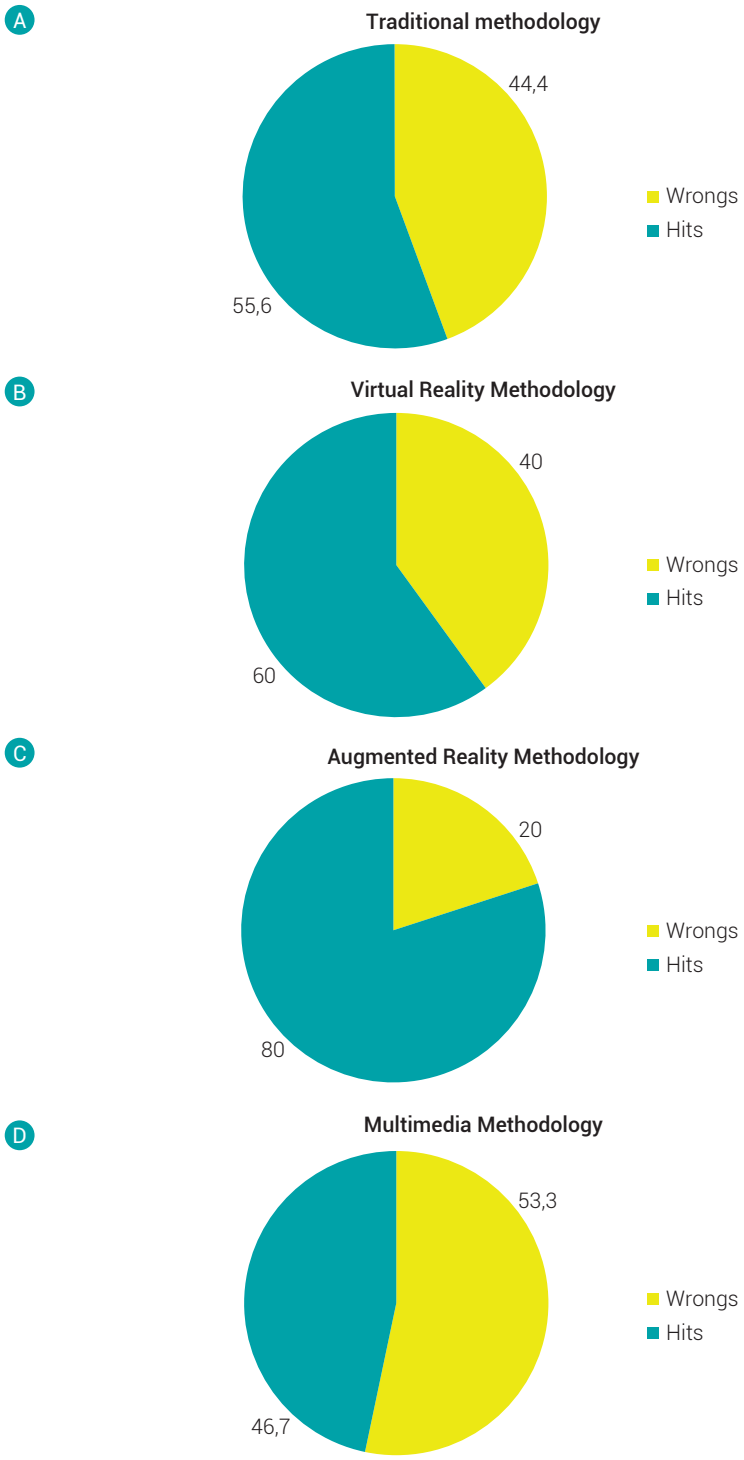

Fig. 8 A) Results of the traditional methodology diagnostic evaluation B) Results of the VR methodology diagnostic evaluation C) Results of the AR methodology diagnostic evaluation D) Results of the multimedia methodology diagnostic evaluation

Source: Own work

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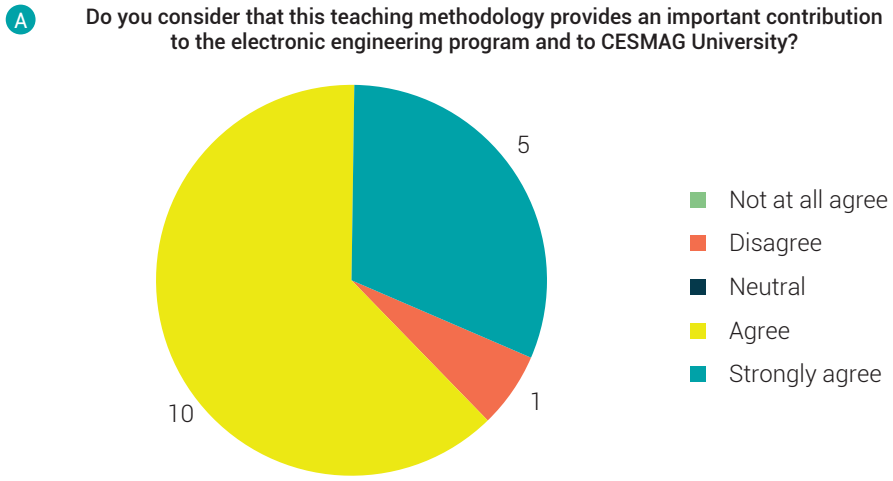
4. DISCUSSION AND CONCLUSIONS

Analyzing the results presented in Fig. 8 leads to the conclusion that students who employed the AR methodology achieved a higher success rate, obtaining 80% in the evaluation. In contrast, those using other methodologies attained 56% with the traditional approach, 60% with VR, and 47% with multimedia. Consequently, it was determined that AR proved more accessible for students to comprehend and adapt to this new tool. By utilizing their cell phones for this activity, they adapted to the new instructions (with the help of the manual), allowing students to understand the experiment at their own pace.

The introduction of these new tools piqued considerable interest among students, as demonstrated in Fig. 9. When asked about whether these methodologies constitute a substantial contribution to the program, 94% of students agreed or strongly agreed. Students were also asked about their willingness to recommend the continued use of these methodologies, with 81% expressing agreement or strong agreement. Hence, students hold a positive perception of these new methodologies and express interest in continuing classes with their assistance. Regarding their understanding of the topic (Lenz's law), 81% of students responded that it was between understandable and very understandable. This indicates a strong comprehension of the topic. When asked about the description of the new methodologies, 94% deemed them adequate or very adequate. Therefore, the development of Lenz's law experiment using these new methodologies was accurate and comprehensible.



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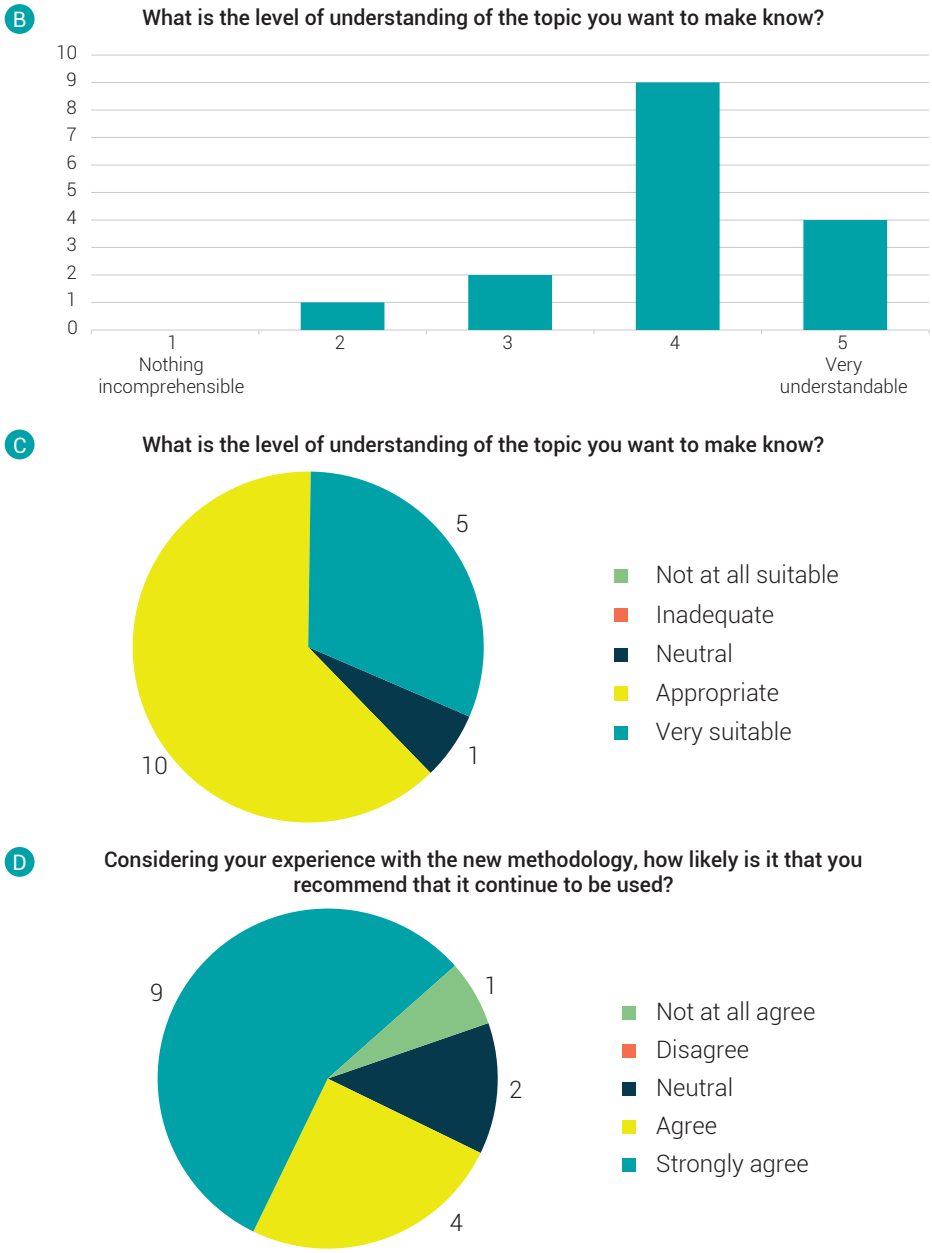

Fig. 9 A) Question about the contribution generated by the inclusion of the tools to the Electronic Engineering program B) Question about the level of understanding of the subject C) Question about the description of the new methodologies D) Question about the possibility of recommending the use of these new methodologies

Source: Own work

While it is true that the research obtained good results during the two tests, further research work is needed so that the results can be more conclusive. In the Fig. 9, it can be seen how the students used the different digital tools.

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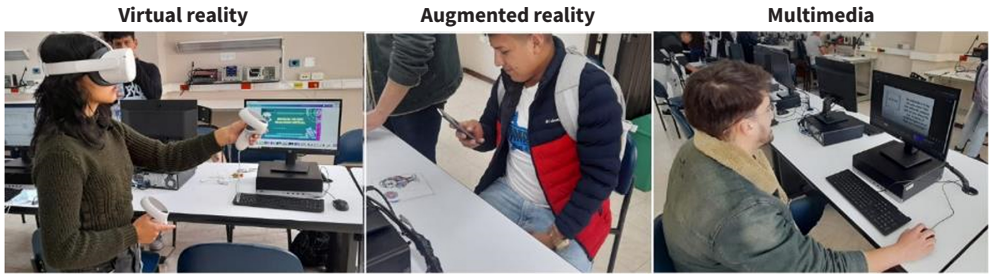

Fig. 10 Students with digital tools
Source: Own work

In summary, AR stood out among the applied tools for its intuitive handling, engaging students quickly in the development of the experiment. Additionally, it was notable for the ease with which students could practice the experiment on their mobile devices.

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