

Teaching Electrical Circuits Through the Virtual Lab

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Abstract: Virtual laboratory technology allows experiments to be carried out under conditions that in some cases cannot be found in the laboratory, as well as access to the use of interaction with laboratory elements in an environment generated by computers. This type of laboratory has allowed the simulation of experiments using devices such as the computer, to increase freedom in carrying out the practices, being able to execute them as many times as desired, at a time according to the student's time availability, without requiring materials or elements. real and without putting the person carrying out the experimentation at risk. The development of a computational tool that supports the apprehension of knowledge in the area of DC electric circuits is presented, the motivation to carry it out was that this topic is taught in a large part of engineering and the existing applications do not emphasize the basic topics, in addition of the scarce supply of free computer programs. The laboratory designed and implemented is made up of six options, four educational and two required in the application; the educational options allow to carry out tests of basic knowledge, review the theoretical foundations of the subject, execute numerical exercises and carry out the assembly of circuits. The application options are for starting and exiting the application. The acceptance of this proposal by the students was high, showing interest in its use, most of the respondents consider it attractive to reinforce the theme.

Keywords: Electrical Circuits, Simulation, Software, Teaching, Virtual Lab.

I. INTRODUCTION

Technological developments, with the convergence of information technology, telecommunications and electronics that lead to the digitization of information, have impacted all fields of life. The adoption of these elements and their integration into the routine of daily living has been due to continuous improvements in hardware and software (more striking, quick response to the actions that are submitted). The perception of the environment, as well as the knowledge and control of it, is being given by the universal digital network created, defined as a collection of different elements, among which are the Internet, communication networks, mobile devices, etc. [1]. In 2019, 49% of the world population connected using Internet services on a mobile device, mobile phone users exceeded 5,000 million, the number of SIM cards was higher than the number of inhabitants on the planet, these are data from the report annual event given by GSMA within the framework of MWC (Mobile World Congress), an event that brings together participants from the mobile industry, attended by executives representing global mobile operators, device manufacturers, technology providers, suppliers and content owners [2].

Examples of technology inclusion are found in the home, where there are appliances that can be programmed according to the family's needs, as well as virtual games for entertainment. In the hospital premises, remote medical consultations can be carried out, the patients are connected to the doctor through the network, the measurement equipment that collects data and uploads it to the cloud are also observed to be analyzed by

specialists who are in a distant geographic location. In industry, technology has made it possible to reduce human effort, carry out processes with greater accuracy, improving the use of raw materials, reducing the risks of handling equipment or substances. Communications have advanced vertiginously, promoting ubiquity as people interact in distant places at the same time through teleconferences with high transmission speeds. The communication equipment is robust and of low weight and size; In the cultural part, where the artistic, musical, literary, among others, meet, the events are broadcast in mass and in real time. The area of education has not been isolated from the technological incursion, a trend in professional training is distance education as coverage is expanded to include different groups of people, there are needed virtual spaces that provide the necessary infrastructure to support this type of teaching-learning, from the offer of academic programs, continuing with the enrollment and enrollment, the spaces for teaching and for practices, to name a few; hence the urgency to incorporate innovative strategies and adjust teaching processes to the continuous changes present in the current knowledge society [3]–[6].

Laboratories are spaces where the knowledge transmitted in theory is reinforced, this important didactic resource allows the student to appropriate the theories, concepts, laws, etc. shown in the theoretical sessions of the different subjects; Hence, it takes different names depending on the geographical context, in North America it is known as “laboratory work”, in Asia, Australia and Europe it has been called “practical work”, while in Latin America and Cuba “laboratory practices”. The development of laboratory practices requires temporal and spatial organization, with environments where activities such as collaborative work, interaction with various sources of information, manipulation of equipment, obtaining answers to problems, are carried out, all these conducive to strengthening both psychomotor and social activities from a disciplinary perspective. As spaces with elements and devices are required to carry out the practical sessions, access can become difficult, since it is because there are established schedules for entry that sometimes do not agree with the student's time availability, or for a limited amount of time. elements that do not meet the demand. A solution to these limitations is the creation and use of Virtual Laboratories [7]–[9].

The Virtual Laboratory is a concept derived from virtual classrooms, where teaching / learning spaces created on computers and connected online by

Internet are proposed; These models reproduce the didactic environments of physical laboratories, in contexts where the possibility of physically bringing students and teachers together is difficult. Thus, virtual environments as a result of technological advances are shown as a revolutionary tool where several people come and can interact with each other and with elements of the laboratory, representing these in such a way that they physically imitate the real elements of the laboratory. In this environment, simulations of an experiment can be carried out, knowing one's own environment, expanding knowledge, working on common projects, which makes its use enriching and attractive [5], [10], [11]. The many advantages of virtual laboratories, including ease of use, increase in laboratory practices without the need for physical presence, feedback from practices, verification of learning, have made these teaching spaces have reinforced their use [11].

Covid-2019 and the time of crisis where mobility is restricted have shown that technology plays a fundamental and decisive role in human interactions, as it provides communication tools that support different processes, such as education. The urgency of having virtual spaces for teaching and learning has been observed and providing tools that make it possible for educational centers to carry out their work of training the country's youth. One of these spaces is virtual laboratories, they are born due to the difficulty of finding computing alternatives, making the use of technology in the development of applications unavoidable to continue with academic activities. However, not having laboratories could trigger a series of inconveniences in the teaching and learning process, especially in the areas of engineering and technologies, which are considered a fundamental piece in the development of countries. It is a contradiction to have engineering faculties dedicated to the areas of information and telecommunications that do not respond to the needs raised today in times of pandemic. In this sense, software systems that allow the student to interact through virtual laboratories are essential to maintain the technological infrastructure and support the processes of education [5], [12], [13]. Hence, in times of personal isolation or difficulty in traveling to laboratories, virtual laboratories can provide students with a useful experience [14].

In the engineering area, teaching requires practice spaces to put the student in contact with reality; if it is limited to the presentation of concepts, including the resolution of exercises, the learning will be insufficient. Laboratory practices

are essential to understand and retain the concepts given in the theory, observation and contrast being necessary to verify results and obtain conclusions. The subject of electrical circuits is based on different engineering, it is approached with theoretical classes accompanied by exercises and reinforced with experimentation in the laboratories of the exposed texts, the latter vital for the appropriation of the concepts, since the student must be able to apply the concepts in a real experiment and draw your own conclusions [14]–[17].

The teaching of the subject of electrical circuits has had several facets, always considering the apprehension of knowledge as a combined relationship between systematized information (of a scientific nature) and non-systematic cultural information (of a popular nature), it has mainly been based on three models: 1. “Heterostructuring”, knowledge is presented in a structured way, the role of the teacher refers to the transfer of knowledge through didactic tools, then the active role in this training process is in charge of the teacher while the student is passive in their academic training. 2. Self-structuring: the pedagogical processes have minimal orientation, therefore the motivation for the student to undertake the task of acquiring knowledge is key, here the role of the teacher is the motivator centered on the student. 3. “Interstructivism”: it is a mix between the theory of Constructivism formulated in 1973 by Piaget and the one proposed by Papert in 1991 called Constructionism, in this model knowledge is obtained through the interactions of the subject with their environment, interaction with the environment is promoted for the understanding and search for knowledge, building a constant evolution in apprehension, hence the student is active in building their knowledge and the teacher becomes an advisor [18]. Regardless of the model used, the demand for attractive pedagogical tools for the student is envisaged that promote the application of activities where real-world practices are involved, as well as the increase of interpersonal skills and motivation of students in the face of pedagogical problems, in such a way that Adverse aspects are counteracted, among which are: difficulty in learning due to the complexity of the content, demotivation and disinterest due to the lack of practical approaches. For this reason, new learning approaches have been proposed where the goal is to provide full and coherent learning with the professional reality present in the software development labor market [19].

The online teaching-learning process using the Internet is carried out in virtual spaces called virtual classrooms, in this environment educational concepts and experiences are shared using communication systems mediated by computers. Their objective is to model or reproduce the didactic environment of physical classrooms, they are used in contexts where it is impossible to attend in person. Due to the different scenarios existing in educational institutions, other virtual spaces have emerged that represent them, such as laboratories and libraries [3], [10]. Virtual Laboratories have achieved great developments in all areas of knowledge, since they constitute a whole system of intellectual exploration, conceived to promote learning, for this reason they have emerged in response to the need for remote interaction between students and teachers, students and students and in general of the entire academic community [17], [20]. In times where technology is immersed in all fields of life, education requires the sharing of courses, seminars, conferences, learning objects, and academic resources among people located in different geographic locations [21].

For the sake of connectivity, it has been possible to have lightweight devices, such as tablets or cell phones, which are widely used in all social strata and age groups since they can be used in numerous situations, mainly for social purposes, but their potential to service in collaborative learning is quite high. Digital technology with a disposition to the social part facilitates social interaction and collaborative practices, where students select and control the rhythm of their learning using various tools, such as videos, audio recordings, group management and storage and use. shared data, to name a few. For this type of teaching-learning, it is necessary to generate spaces where students develop physical and intellectual abilities and competencies that allow them to articulate and apply knowledge to solve problems in the real world [18].

The project that is exposed is the creation of a virtual environment where technology, pedagogy and didactics are integrated so that students from the D.C. they can validate their knowledge and reinforce the theory seen in class; It is an environment where the essential components of circuits, resistors, inductors, capacitors are observed, in addition to an explanation of their construction and operation, additionally there are solved and proposed exercises of the basic laws, such as Ohm's law and powers. Once this tool was built, it was made available to the students of the Introduction to Electronics subject, in the

Introduction to D.C. Electrical Circuits module, who validated its operation and contribution to their learning process.

II. METHODS

A. Research process design

Construction of the software was based on the methodology proposed by Guevara and Luengas 2008 [13], where a method is proposed to develop the research process that includes: definition of the topic, description of the problem, definition of the objectives, justification, development of the frame of reference and determination of the methodological design, Figure 1. From these elements, ideas are generated about the topic to be addressed, reflecting on the needs and problems, to design and build the laboratory, and subsequently be validated.

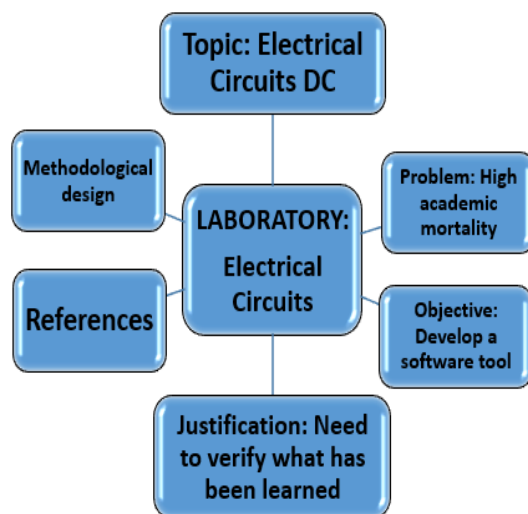


Figure 1: Research process to develop the virtual circuit Laboratory D.C. Adapted [13].

The theme of D.C. electrical circuits was chosen. Since it is a recurring teaching topic in the engineering area, in addition to the fact that in the Electronics and Electricity programs of the Universidad Distrital Francisco José de Caldas, Bogotá, Colombia, it presents high academic mortality, the repetition of this subject is high in comparison with another of the same semester. Conducting interviews with students who take the course about the loss of this, it was evidenced that there was not easily accessible, striking, free study material that allows checking what was taught in class, this lack means that knowledge is not reinforced or validated. In consideration of the above, a project was proposed whose general objective was: To develop a software tool to

accompany the students' work about Circuits D.C. The following were established as specific objectives: 1) Creation of a virtual laboratory for Electrical Circuits D.C. basic. 2) Writing of subject scripts adapted to the virtual methodology

With the established goal, we proceeded to set the motivations that lead to the development of the project: to provide a computational tool that allows students or people interested in the subject of Electric Circuits D.C. Review and test the knowledge acquired in the classroom, this should facilitate the user's self-evaluation in an active way, be easy to use, free, can be installed on any computer, with self-content to provide what is necessary in the realization of the practice and contain the concepts to be worked on during the practice.

The agreed theme to work on was consulted, allowing the construction of the state of the art and the theoretical framework, determining the basic aspects addressed in the tool: Basic concepts, electric charge, electric field, voltage, current, electric power and resistance. Elements: resistor, capacitor, inductor. Circuit laws: Ohm's Law, Kirchhoff's Law, Power Law. Resistive arrays: series, parallel.

The agreed methodology was an adaptation to the one proposed by Guevara and Luengas [12], who propose that the research be carried out in three phases. A first phase to establish the requirements of the interaction system. The second for the design and construction of the software interface that contains the elements of the basic laboratory. The third allows verification of operation. The stages contemplate a series of activities to be carried out in order to obtain a functional laboratory, these can be carried out using a spiral methodology, in such a way that at the beginning an incremental version is carried out (sketch of the model proposal), consistent with improved versions and in the last iterations the production of software that increasingly resembles the designed system, Figure 2.

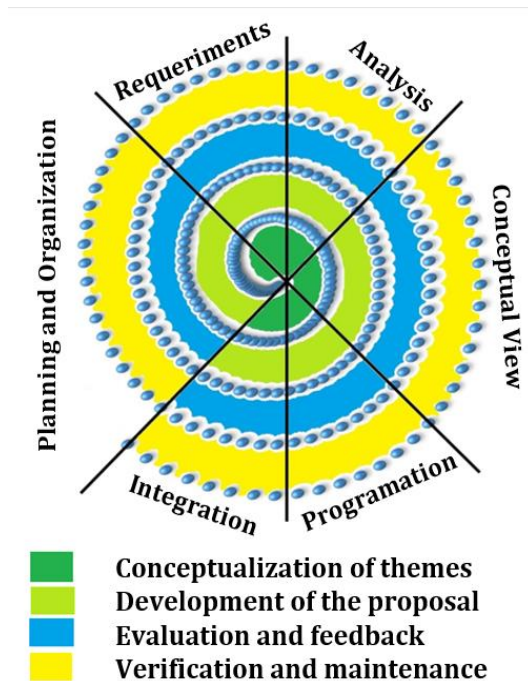


Figure 2: Methodology adopted for the generation of the virtual laboratory of electrical circuits D.C.

The phases assorted in the methodology included:

1. Planning and organization of each of the stages in order to define the goal of each one, the associated activities, the profiles of the group of people who will actively participate in the execution of the project and the technical tools required.

2. Establish the requirements with the business modeling, determining the different characteristics that the software must meet and the main processes to be carried out; therefore, process diagrams, the domain model and a glossary of terms are established.

3. Perform the analysis to study the requirements set in the previous stage and build a model proposal where the essential components of the system and its operation are established, defining the technology, the software to be used, the initial list of use cases, the debugging these, the model and the documents of each use case.

4. Propose a conceptual view of the laboratory, building sequence, collaboration and activity diagrams for each use case, the state diagram and the analysis model.

5. Carry out the programming tasks of the systems that make up the laboratory, making use of

deployment diagrams, packages and components and the code of each one of the subsystems.

6. Carry out integration tests of the systems that make up the laboratory, for verification and improvement.

B. Laboratory Design

The software developed consists of an application that can be installed on any computer that has Windows as the operating system. This operating system was chosen for being the most popular; The intention of the development is focused on reinforcing the learning of students interested in the area of D.C. electrical circuits, with fundamental topics of the subject, such as: Basic elements, such as resistance, capacitor and coil; Circuit laws, Ohm's law, Kirchhoff's laws, power law; Resistive arrays.

The virtual space of the D.C. electrical circuits laboratory It was designed to have: Support of theoretical material, where the basic elements of D.C electrical circuits are exposed; Questionnaire to check if the concepts are clear; Perform exercises and see if they are correctly solved; Construction of resistive arrangements to verify proper connection. Hence, the application is composed of six options, four educational and two required in the application: Home, where the use of the software is welcomed; Questionnaire to carry out basic knowledge tests; Concepts shows the theoretical foundations of the subject to be studied, in such a way that if there are knowledge gaps, they can be clarified in this option; Exercises proposes a series of numerical exercises to reinforce the theoretical part of calculations, making use of the basic laws of circuits; Practice proposing to carry out the assembly of circuits; Exit is used to end the application. The Questionnaire, Exercises and Practice options are validated at the time of their execution, in such a way that the student can know the successes either in the answers or in the assembly. Each of the didactic options that the software allows is made up of: Images, with graphic representations of each of the elements; Text, to make known the written description.

The software chosen was Matlab® as it allows the creation of graphical user interfaces (GUI-Graphical User Interface in English), where the user interacts with the digital information found in the application through a graphical simulation environment to perform the different options presented by the laboratory. Matlab® is a simulation software package used in engineering for programming and numerical calculation, it allows the design, analysis, visualization and simulation of

electrical and electronic circuits carried out in a graphical interface (GUI). The interface can be made extremely realistic, for students to use a mouse and graphics options to create diagrams. In previous studies, groups of university engineering students were investigated in an electrical circuit class, noting that Matlab® provides students with a pleasant environment to develop their knowledge of electrical behavior.

The interaction in the GUI is WYSIWYG (What you see is what you get, 'what you see is what you get'), also called object-action-interface (OAI), the objects present in the graphical interface act representing the action to be taken. The use of images favors the apprehension of knowledge, since cognitive psychology is used making the brain work more efficiently, reducing verbal processes and therefore the extra layer of interpretation to the communication process. Another advantage associated with the use of GUIs is the almost immediate response of an action within the software, this allows to know the evolution in the execution of the practice.

The design was made taking into account the objective of the application, as well as the characteristics and operation. The characteristics of having an application with a friendly, intuitive and easy-to-use interface have been set, where fundamental issues of D.C. electrical circuits are integrated, and to be able to install it on a computer that has a Windows operating system. As for the operation, once you start using the application, the main menu is presented with the different options in the form of tabs; Once the desired option is chosen, the educational content is accessed, as mentioned, the images that represent the elements are displayed, along with their description and their symbol, so the student can identify the characteristics of each element contained in the application, developing their process Learning. With this information, the use case diagram was created, in order to know the communication specifications and the behavior of the system, as well as the interaction of the application with the user. Figure 3 shows the diagram to observe the relationship between the actors and the use cases in a system.

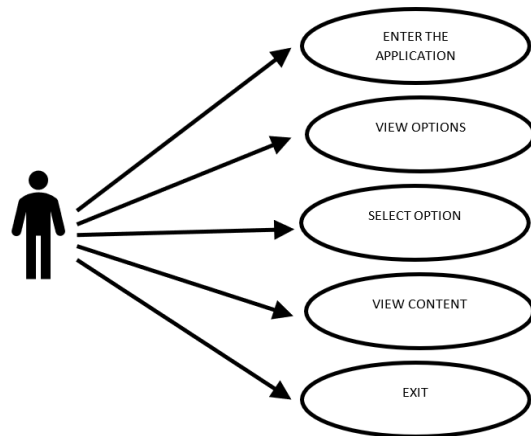


Figure 3: Diagram of use cases of Laboratory of Electric Circuits D.C.

The understanding of the connection between the application processes is observed in the sequence diagram of Figure 4, there the dynamic behavior of the laboratory is described, emphasizing the chain of information exchanged by the objects. The sequence diagram represents events in chronological order to describe how objects (and instances) exchange messages in a certain order. Objects represent characteristics of an element of the system. In a system, requests are made and responses are constantly sent. The recipient makes decisions based on the specific request and their own predefined rules. The possible decisions and interactions are represented in this diagram in linear form.

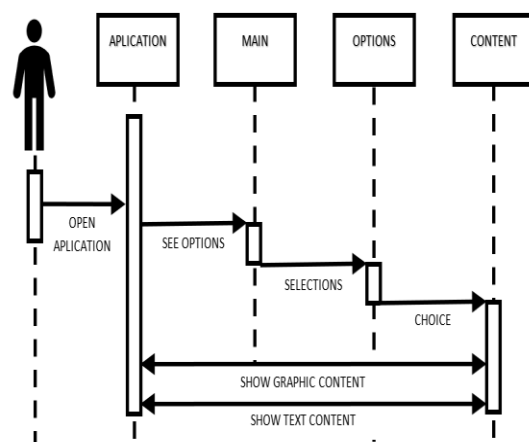


Figure 4: Laboratory sequence diagram.

Once the application is accessed, basic information about the software is displayed, there are the laboratory exploration options. You can select one of them and navigate within the content.

III. RESULTS

In the absence of an experiential learning experience in a physical laboratory, there are alternatives that allow the behavior of electrical circuits to be simulated in detail. This article presents a simulator that allows you to practice the concepts learned in class for a better understanding, making use of free interactive software, free to use, which can be downloaded to any mobile device or desktop computer. It is mainly delivered to the students of the Francisco José de Caldas District University in Bogotá, Colombia, since most of them are of low economic resources and cannot buy didactic tools. The purpose of the electrical circuits laboratories is to allow students to develop analysis and design capabilities through the construction of circuits, there students apply their theoretical knowledge in the integration of electrical materials and components such as resistors, capacitors, inductors and instruments. of measurement and generation of energy such as sources, multimeters, function generators, etc. A particular configuration or topology called an electrical circuit is created. Under current conditions, with restricted mobility to classrooms due to the pandemic, students have been deprived of the accompaniment of teachers to solve doubts and carry out laboratory practices, for this reason laboratory practices were designed considering the software available online and specific topics seen in class.

Figure 4 shows the initial image of the proposed Virtual Laboratory of Electric Circuits D.C, there are the five tabs to select the action to be chosen.

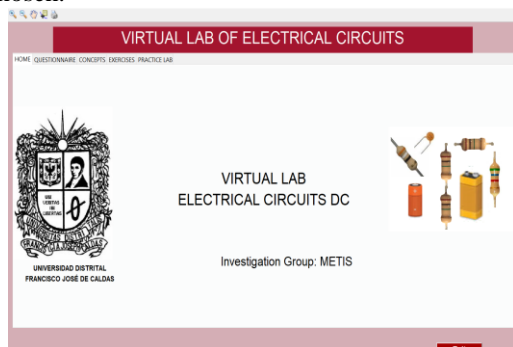


Figure 4: Initial screen of the D.C. Electric Circuits Virtual Laboratory.

1. HOME is the presentation of the laboratory.

2. QUESTIONNAIRE allows to validate the concepts of the subject. A series of questions are presented to be answered using the multiple-choice technique. When the answers are correct, the message is displayed: “EXCELLENT, YOU HAVE

12 POINTS”, otherwise it appears: “OOOH, YOU HAVE FAILED, TRY AGAIN”, Figure 5.

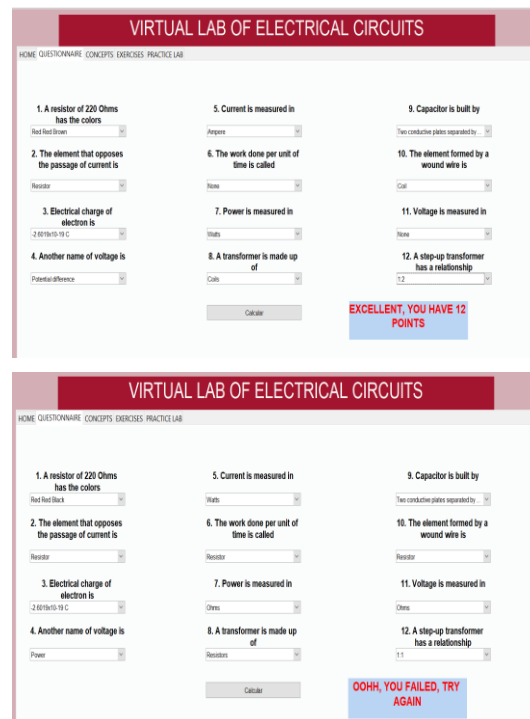


Figure 5: QUESTIONNAIRE screen.

3. CONCEPTS, if the student needs to remember the theoretical bases of circuits, in this option the fundamental concepts are presented, as well as the description of the elements used in circuits such as Resistors, Inductors and Capacitors, in addition to the explanation of the fundamental laws in the area, Ohm's Law, Kirchhoff's Laws, Power Law, Figure 6.

4. EXERCISES present a series of numerical approaches to be developed using Ohm's Law, Power Law, Kirchhoff's Laws. Once the proposed exercises are carried out, the student selects the result, and the application verifies the correct answer by throwing messages like those shown in the QUESTIONNAIRE option.

5. PRACTICE proposes a series of resistors assemblies, the circuit to be assembled is indicated either graphically or text and the student must move the elements so that they coincide with the proposal; As in EXERCISES and QUESTIONNAIRE, it gives some messages once the assembly has been carried out.

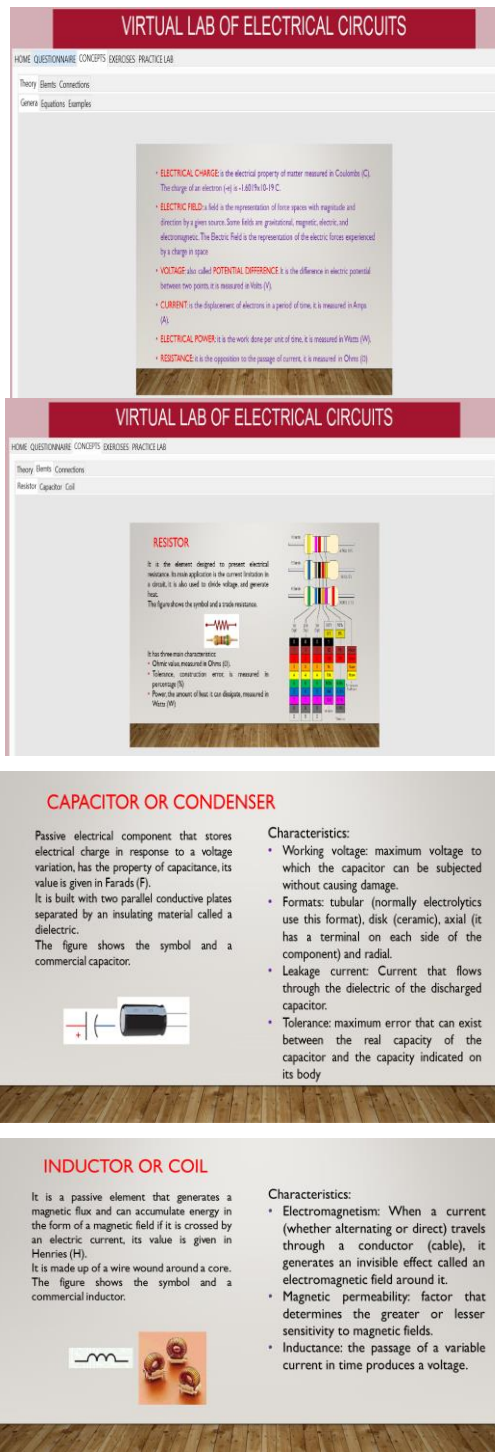


Figure 6: Contents of the CONCEPTS option.

Once the development of the application is finished, it is installed on computers in order to carry out functional tests. It is verified that the menu options are functional and correctly display the graphic and text content. For this, the entry to

each option is evaluated and the exit button is used, resulting in correct operation in all the tests.

The evaluation of the application, a critical element in Software Engineering, allows to guarantee the quality of a software, in addition to verifying if it has the correct specifications, design and coding. This evaluation is carried out once a functional interface prototype has been created, there is a wide range of possibilities to carry out the evaluation, starting with an informal test like the one described in the previous paragraph, until observing the user's response when using the application, going through assessment using questionnaires. The evaluation included factors of the evaluation criteria used by educational software evaluation consortium, such as ease of use, versatility, audiovisual quality, content quality, navigation and interaction, novelty and use of advanced technology, pedagogical aspects, didactical resources, stimulates the initiative and self-learning. This type of evaluation is knowing as evaluation for action because it provides information that is needed to take decisions. The evaluation of the Virtual Laboratory of Electric Circuits D.C. was carried out using the Nielsen method, where the impressions of students are collected once they used the application. Twenty students were selected from the Electrical Circuits course, see figure 7. The questionnaire uses the Lickert scale, with integer numerical values between 1 and 5, where 1 = Totally disagree and 5 Totally agree, the questions are showed in Table 1. The scores were used in determining the internal consistency of this software by Kendall's Coefficient of Concordance method. A value of 0.941 ($p > 0.05$) was obtained.



Figure 7: Students using virtual lab.

Table 1: Items of evaluation.

No.	ITEM
1	It was very easy to learn how to use this system
2	Using the system was not frustrating
3	I had errors when using this system
4	It is easy to identify common elements at all levels of the system
5	The different elements of the interface contain simple and concrete information
6	Images are clearly distinguished
7	The way I navigate is simple
8	The presentation of the interface appeals to me
9	I think it is an entertaining way to learn
10	The system is fast and efficient.

The mean of the responses obtained in the evaluation of the application is shown in Figure 8. The acceptance of the generated software was high, with a score of 4.8 out of 5. The lowest score was in the errors made when using the software, a possible explanation is that the students did not follow the directions given. Overall, the students found it an enjoyable way to review the concepts taught in class. Test showed that in functionality the software is ease of use, the people used the educational software without having to read the manuals exhaustively. The content's quality was high, the information is well structured, and does it adequately distinguish the objectives, context, results, multimedia resources, the content is validated, and it is related with situations and problems of student's interest; also, examples, simulations and graphs are part of the system. In adaptability, the software is versatility, and it is easily integrated with other educational environments, this software allows for new techniques and better learning. It is allowing for activities that keep the curiosity and the interest of the students in the content, this a great pedagogical aspect. Other advantage are stimulation of the initiative, self-learning, and cognitive effort of the activities. The efficiency is in visual quality, there is no excess of information, it has a rigorous scenario design which includes title, menus, graphics. Additionally, the software has a good program structure that allows easy access to content and activities, the program execution is efficient and with no operational errors, the navigation system is transparent, allowing the user to control actions.

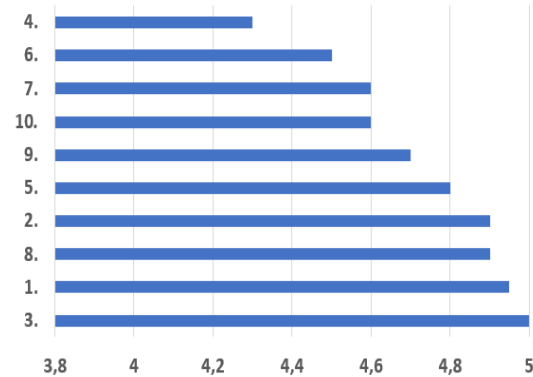


Figure 8: Mean of the responses to the questionnaire.

IV. CONCLUSIONS

The use of virtual laboratories in learning has an important role in the apprehension of knowledge. Several studies have shown that the virtual lab can replace classroom labs [14] - [17]. Brinson [22] concluded that both the virtual laboratory and the classroom are pedagogically equivalent, both have great benefits for learning, this after analyzing 56 articles that evaluate the performance of the virtual laboratory with respect to classroom laboratories.

Today, the development and use of virtual laboratory is progressing immensely. It seeks to help students understand and reinforce the concepts given in class. The virtual laboratory is a simulation program with shared resources on the network developed so that users can remotely put into practice the knowledge acquired in the classroom [13], [23]. The implementation of the virtual laboratory requires several considerations: First, to introduce students to the use of these computational tools. Second, to provide the adequate concepts for the use of this laboratory to be successful. Third, plan the practices to resemble the exercises done in the classroom. The efficiency of the use of virtual laboratories in teaching depends on the inclusion methodologically and pedagogically competent [22], [24]–[26].

The use of virtual laboratories represents an opportunity for the teacher to stimulate the student with educational technology, the responsibility to learn by himself and transfer his learning to the real world; It also involves the challenge of developing game-like materials with educational interests. Constructivist theories of teaching are those that provide the most support today for the use of skills that students already possess and their use to solve new problems, acquiring useful learning for the future [26]. Using methods that involve computer technology in the classroom brings an advantage for the teacher, since students are more stimulated to

learning using virtual environments. When the real laboratory is not possible or convenient, the virtual laboratory is a good substitute or at least for training before performing dangerous practices, especially if there are mechanical or virtual reality simulators instead of a simple one screen [27].

Some of the main reasons for the use of these computational spaces are: decrease in the investment of expensive machines, the expansion of access to laboratory equipment, in the laboratories carried out by groups of students, direct and cooperative work can be observed but it is necessary reinforcing autonomous work, limited availability of free time in laboratories to carry out practices again that allow consolidating knowledge on a specific topic, reducing the cost of consumable items, little ease of traveling to the university classrooms, to name a few reasons [26], [27].

But it is importance a methodology in the design and implementation of this tools, for this reason we propose a research process with three phases. This design allows build laboratories to response a real problem.

The basic DC electrical circuits laboratory allows the simulation of experiments in an easy and safe way, with presentation of results in graphic and text form. The system allows monitoring and controlling the work of students, by combining monitoring tools when using the software.

It was possible to show that the computational tool generated has high acceptance among students, which may indicate the existence of feasibility of use of the system, since it allows exploring and reviewing the basic concepts of DC electrical circuits, in times dictated by each student, and make use of the system as many times as you like.

Taking into account the results of the evaluation of the software, the application is expected to collaborate in the apprehension of knowledge, in addition to guiding in the implementation of real laboratory practices in order to strengthen scientific competence in the area.

Creation of free virtual labs using the Matlab® GUI is unknown, even though this software is widely used in Engineering. This is a first attempt to incorporate free technological tools in the teaching-learning processes aimed at students of electrical circuits at the Universidad Distrital Francisco José de Caldas. In the future, educational software is expected to include other circuit arrangements and other elements.

REFERENCES

- [1] F. Sáez Vacas, *Cultura y Tecnología en el Nuevo Entorno Tecnosocial*. Madrid: V.A. Impresores. S.A., 2011.
- [2] GSMA, "The Mobile Economy," Barcelona, 2020. Accessed: Mar. 14, 2020. [Online]. Available: <https://www.gsma.com/mobileeconomy/>.
- [3] M. Aldas et al., *La educación a distancia y virtual en Ecuador. Una nueva realidad universitaria*, Primera. Loja: Universidad Técnica Particular de Loja, 2013.
- [4] L. A. Luengas C., *Laboratorio virtual de destilación apoyado en un sistema de captura de movimiento*. Bogotá: Editorial UD, 2013.
- [5] L. A. Luengas C., G. Sánchez, and J. C. Guevara, "Laboratorio Virtual: Herramienta pedagógica de apoyo en el proceso de enseñanza – aprendizaje Autores," in *Educación Digital y Gestión del Talento Humano en Iberoamérica*, Medellín: CIMTED Corporación, 2017, p. 721.
- [6] UNESCO, *Texto 1 Innovación Educativa*. Lima: Cartolan E.I.R.L., 2016.
- [7] O. M. Buenaventura, "Realidad Aumentada Como Estrategia Didáctica En Curso De Ciencias Naturales De Estudiantes De Quinto Grado De Primaria De La Institución Educativa Campo Valdés," *Universidad De Medellín*, 2014.
- [8] Á. L. Torres, "Empleo del laboratorio asistido por ordenador en la enseñanza de la física y química de secundaria y bachillerato," *Rev. Eureka sobre Enseñanza y Divulg. las Ciencias*, vol. 7, no. 3, pp. 693–707, 2010.
- [9] E. A. Espinosa-Ríos, K. D. González-López, and L. T. Hernández-Ramírez, "Las prácticas de laboratorio: una estrategia didáctica en la construcción de conocimiento científico escolar," *Entramado*, vol. 12, no. 1, pp. 266–281, 2016, doi: 10.18041/entramado.2016v12n1.23125.
- [10] G. A. Torres Samperio, "Espacios virtuales de experimentación cooperativa caso de estudio: Laboratorio virtual de cinemática," *Universidad Autónoma del Estado de Hidalgo*, 2001.
- [11] L. A. Luengas C., G. Sánchez, and S. M. Cárdenas, "New pedagogical tools: virtual laboratory," *Rev. VISIÓN ELECTRÓNICA*, vol. 9, no. 2, 2015.
- [12] R. Felder and L. K. Silverman, "Learning and Teaching Styles in Engineering Education Richard," *Engr. Educ.*, vol. 78, no. 7, pp. 674–

- 681, 1988, Accessed: Oct. 27, 2020. [Online]. Available: <http://www.ncsu.edu/felder-public/ILSpa.html>.
- [13] J. C. Guevara and L. A. Luengas C., "Laboratorio virtual de destilación química," *Vínculos*, vol. 5, pp. 42–50, 2008.
- [14] M. Z. Rahman, "Teaching An Electrical Circuits Course Using A Virtual Lab," *J. Coll. Teach. Learn.*, vol. 11, no. 4, pp. 85–92, 2014, doi: 10.19030/tlc.v11i4.8853.
- [15] C. Arguedas-Matarrita et al., "A teacher training workshop to promote the use of the VISIR remote laboratory for electrical circuits teaching," 2017, doi: 10.1109/EXPAT.2017.7984351.
- [16] J. Torres and J. Sweeney, "Integrated lecture-lab approach with virtual instrumentation for teaching electrical circuits to bioengineering students," in *ASEE Annual Conference and Exposition, Conference Proceedings*, 2008, pp. 2–10, doi: 10.18260/1-2--4001.
- [17] L. L. Scarlatos, A. R. Pratama, and T. T. Tchoubar, "The Virtual Breadboard: Helping Students to Learn Electrical Engineering at a Distance," 2017.
- [18] A. Barros de Sales and C. Boscaroli, "Uso de Tecnologias Digitais Sociais no Processo Colaborativo de Ensino e Aprendizagem," *risti*, vol. 37, no. 6, pp. 82–98, 2020, doi: 10.17013/risti.37.82–98.
- [19] V. Arevalo, J. M. Vicente-del-Rey, I. Garcia-Morales, and I. Rivas-Blanco, "Minivideos tutoriales como apoyo al aprendizaje de conceptos básicos para un curso de Fundamentos de Control Automático," *Rev. Iberoam. Automática e Informática Ind.*, vol. 17, pp. 107–115, 2020, doi: <https://doi.org/10.4995/riai.2020.12156>.
- [20] J. I. Rodríguez García, E. Turienzo Santos, and J. J. González González, "¿Mejora la incorporación de un simulador virtual las capacidades en cirugía endoscópica adquiridas con simuladores inanimados?," *Cir. Esp.*, vol. 86, no. 3, pp. 167–170, 2009, doi: 10.1016/j.ciresp.2009.04.008.
- [21] H. Trefftz et al., "Ambientes virtuales colaborativos en cursos de matemáticas para ingeniería soportados por redes de alta velocidad," *Rev. Educ. en Ing.*, vol. 8, pp. 13–25, 2009.
- [22] J. R. Brinson, "Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research," *Comput. Educ.*, vol. 87, 2015, doi: 10.1016/j.compedu.2015.07.003.
- [23] M. Burghardt, P. Ferdinand, A. Pfeiffer, D. Reverberi, and G. Romagnoli, "Integration of New Technologies and Alternative Methods in Laboratory-Based Scenarios," in *Advances in Intelligent Systems and Computing*, 2021, vol. 1231 AISC, doi: 10.1007/978-3-030-52575-0_40.
- [24] Z. Laouina et al., "Manufacturing and Developing Remote Labs in Physics for Practical Experiments in the University," in *Advances in Intelligent Systems and Computing*, 2021, vol. 1231 AISC, doi: 10.1007/978-3-030-52575-0_16.
- [25] N. Strenger and S. Frerich, "How to Design Digitalized Laboratories?: Lessons Learned from Implementing Virtual and Remote Labs," in *Advances in Intelligent Systems and Computing*, 2021, vol. 1231 AISC, doi: 10.1007/978-3-030-52575-0_8.
- [26] K. I. Gamor, "Insights on identifying potential types of guidance for supporting student inquiry when using virtual and remote labs in science," *Educ. Technol. Res. Dev.*, 2021, doi: 10.1007/s11423-020-09928-5.
- [27] K. G. Johnson, S. S. Sullivan, A. Nti, V. Rastegar, and I. Gurubhagavatula, "The impact of the COVID-19 pandemic on sleep medicine practices," *J. Clin. Sleep Med.*, vol. 17, no. 1, 2021, doi: 10.5664/jcsm.8830