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Educational Tool for the Qualitative Analysis of Electric Circuits

Diego M. Rivera-Pinzón*, Jimmy W. Ramírez-Cano and Hugo D. Marín-Sanabria

Universidad Pedagógica Nacional, Bogotá, Colombia; dmrivera@pedagogica.edu.co, jwramirez@pedagogica.edu.co, hmarin@pedagogica.edu.co

Abstract

Objectives: This article presents a strategy for the qualitative analysis of electrical Circuits. The objective is to serve as a supporting material for the instruction on electrical circuits, framing its development within the trend of constructivism. **Methods:** The computer tool developed entails an educational proposal that presents a methodology to support the instruction of concepts related to the dynamic response of electrical circuits with resistive, capacitive, and inductive elements. In the application, the magnitude of the variables is represented in terms of the height of the electrical symbols; the height can be modified by the user to make variations in the dynamics of each circuit in real time. **Findings:** There are several computer tools for the analysis of circuits in the market; however, this work presents a didactic alternative that favors qualitative data, in contrast with popular tools that grant privilege to quantitative data. It has been identified that the application allows showing students' mistakes in the basic concepts, as well as it allows the strengthening of the learning process thanks to its high visual component. This proposal uses activities of guidance and discussion in relation to key concepts of each circuit studied. **Application:** This document presents the overview of the tool, its graphic user interface, the didactic proposal suggested for its use, and the methodological aspects required for its use, including the rationale for the suggested activities.

Keywords: Electric Circuits Education, Educational Software, Qualitative Analisys, Science Education, Teaching Strategies

1. Introduction

The software: "Tool for the Qualitative Analysis of Electric Circuits" appears as a didactic alternative of support to the instructor in the space of analysis of basic electric circuits with DC feeding. The instrument is pedagogically supported from the building of knowledge by using the epistemological trend of constructivism, offers elements to be used as a support to the experimental activities by granting a privilege to the information of qualitative order.

The purpose of the software is to bring to the classroom activities that can be mediated with the use of this instrument, which ascribes to a new technologic era, the era of virtuality and telecommunications. This fact fosters the innovation in curricula, as well as strategies that impede the continuity of memorization and reading without deep understanding of the elements that science and technology have built. This situation makes evident a clear breakup between what is taught in science and technology, what is expected for the student to think, what scientists discover and demonstrate from the interrelations that are promoted in the dynamics of evolution of diverse systems, and what technology is able to develop; in other words, a distance between the scientific and technological thinking that is expected to be encouraged in students and the scientific knowledge produced by science and the technological products of their daily life[1].

The pedagogical basis of the software is the paradigm or epistemological trend of constructivism, which refers to the individual as such in aspects related to the cognitive, affective and social realms. It is stated that these aspects are not the result of the environment or the internal conditions; instead, this individual is built on its own, because of the relationship between these spheres.

**Author for correspondence*

Based on this statement, it could be inferred that from the constructivist stance, knowledge is always the information that a person builds up from the reflection of his or her own actions[2]. It would not be a copy of reality, but a "construction" in the hands of human beings, based on individual schemes that keep relation to their environment[3]. The construction of this knowledge is strongly linked with the representation that is obtained from the new information collected, and another action, internal or external, in relation to such information.

In this way, the software presents two stages as a support of the activity. On the one hand, it presents the typical orientations of the use of the software; and on the other hand, the activities of discussion in which some questions are formulated to make the instructor mediate the debate with the explanations that students have elaborated. These stages entail the construction of group explanations about the observations of the instrument[4]. From this stance, learning does not become a static process that grants privilege the memorization of processes and theories; instead, it is a changing process and in full contextual contact, which favors the conceptual and epistemological change with the active participation of its members[5].

It is expected that the process be strengthened by suggesting to the student the development of projects that use basic electric circuits. In this way, active learning is expected on the student's part, as well as better results in activities that require the use of quantitative data and evaluative processes[6]. Additionally, it is expected that the use of guided exercises, supported by the orientation of the instructor as a strategy, redound to high levels of satisfaction on the student's part, and become a motivational element, increasing his/her level of analysis in a significant form[7].

A no less important element that is present in the development of the software is the use of color and its relationship with the variables in analysis. Previous studies have shown good results in analyses and representations of circuits that combine the use of color with mathematic symbols (variables)[8].

The initiative started after identifying the strong tensions in the experimental activity; on the one hand, the limitation in laboratory equipment, and on the other hand, the way in which the laboratory activity is oriented, granting privilege to the demonstration or verification of the theories that science has formalized, showing an already finished process that does not belong to an adequate method that allows the comprehension and construction of explanations that are distinctive of the scientific practice[2,9]. A view like the one described above makes visible a separation between the theory and the experiment. On the one hand, it does not recognize the theory in the processes of design of experimental activities, and otherwise, it does not acknowledge that the experimental activity does not intervene in the attainment of theories, since this is an activity of taking measurements and data for their posterior manipulation. This situation contrasts what the philosophical studies have described[10–12].

A primordial objective of this software is the motivation of students to the laboratory work; in other words, the objective is to avoid that the student is prejudiced to think about boring and unproductive works when providing solutions to low-income laboratories, by offering activities that promote discussion as well as individual and group analysis. These options have produced good results in research projects that seek to improve the results when evaluating, as well as to allow better performance rates in future professionals[13].

Finally, it is relevant to indicate that the relationship between theory and experimentation suggest that a form of these relationship is hidden or little evident in each image of knowledge because of these relations. A Hidden form of relation is necessary to be explored to improve the understanding of the phenomenon of study[15]. This statement contains relevant consequences, but that is not used in practice, although the activities in the class-room grant privilege to memory tasks, and the evaluative activities focus their attention on tests that measure the level with which a topic has been memorized[2,15]. This system solves the kind of problems that can be found at the end of a chapter of a textbook, and therefore reducing the interaction with the phenome-non studied, as well as the possibility that the student build up his own way of thinking through experience, enabling him to communicate his world views to others[1,16,17]. For this reason, this software grants privilege to qualitative results, which allows the student to be able to build up concepts from observation.

2. General Aspects

2.1 Mechanics

The global functioning of the program begins with a very simple notion: Next to the components there are some red-colored letters with a black arrow crossing them

(Black color in the figures). These letters represent a variable that can be modified. Basically, the only thing that the user should know is how to change the amplitude of those variables, which is done by clicking and holding over one of the letters, and then, by dragging the pointer vertically up or down. The idea is that the size of the letter is associated with the value of the magnitude of the variable in a direct proportion; therefore, if the letter has a small size, a low value in the magnitude is expected; and instead, if the letter has a large size, a high value in the magnitude of the variable is expected. In the Figure 1, the demonstration that the software has is presented, where he mechanics of the program are illustrated.

The modifiable variables depend on the scheme of each circuit, always being identified by their red color. There are two types of variables that are modifiable in this program: the sources (voltage or current) and the resistances. The rest of elements are not modifiable because they would be dependent variables. The results of the changes in the variables update in real time; in other words, changing the size of a variable makes the information of the dependent variables update, either the Zero-order system (an only-resistive circuit) or a first-order system (a circuit with a capacitor or an inductor).

2.2 User Interface

The program's user interface is integrated by three parts. The work area is located covering most of the space of the screen, composed of the circuit and its components. To the left, there is a menu that allows the selection of the circuit with which the user is going to work. Finally, the lower area includes tabs that contain information related

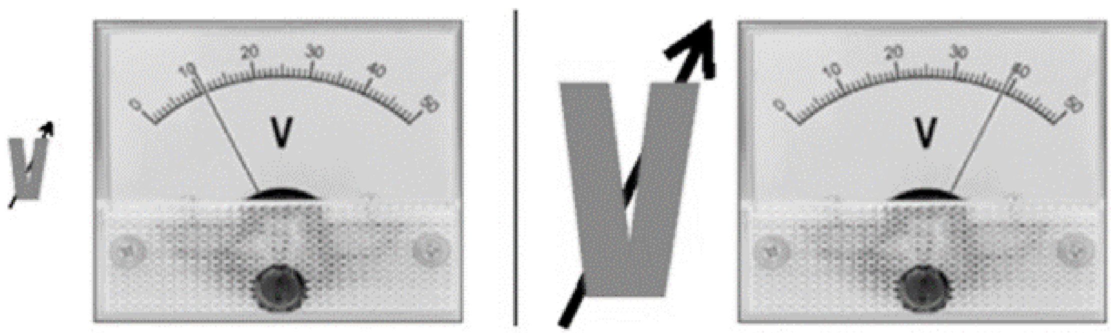


Figure 1. Demo of the program. The size of the letter represents the magnitude of the variable. Source: Authors.

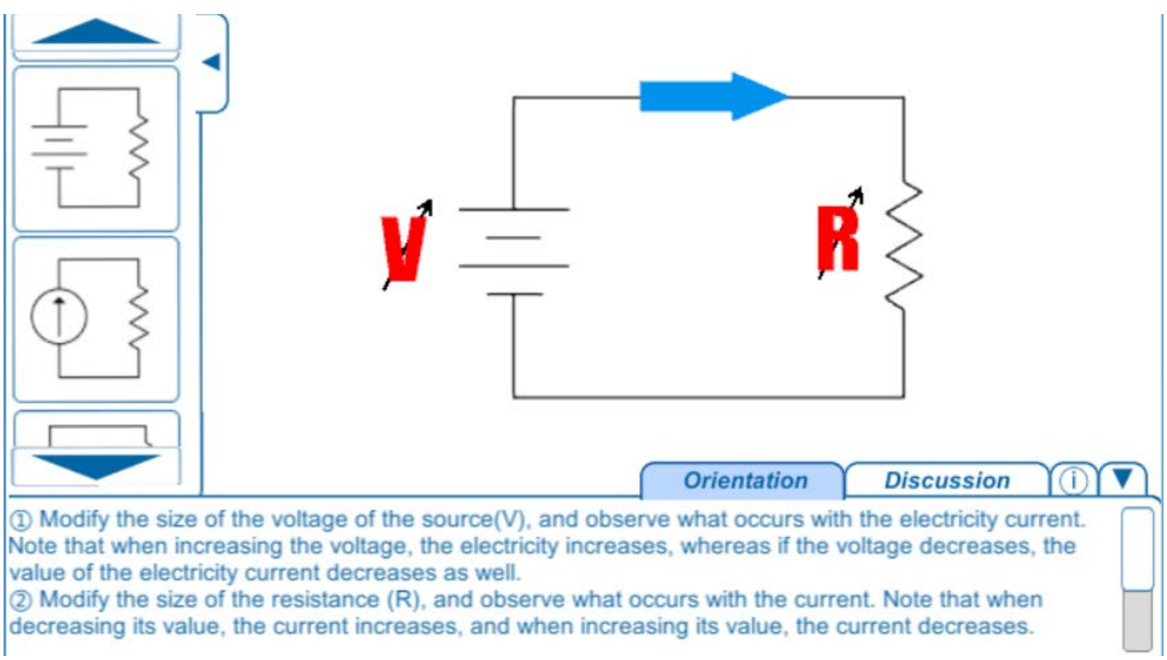
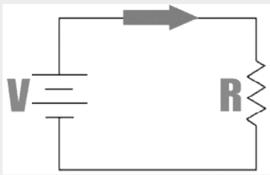
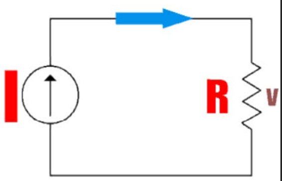
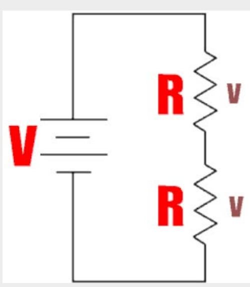
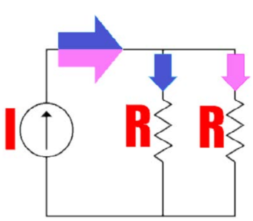
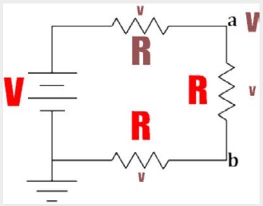
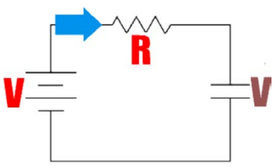


Figure 2. Screenshot of the graphic interface of the program. Source: Authors.

Table 1. Circuits and orientations-discussions associated to each one. Source: Authors

Circuit - Concepts	Orientation	Discussion
 The current is directly proportional to the voltage, and inversely proportional to resistance.	Modify the size of the voltage of the source (V), and observe what occurs with the electricity current. Note that when increasing the voltage, the electricity increases, whereas if the voltage decreases, the value of the electricity current decreases as well. Modify the size of the resistance (R), and observe what occurs with the current. Note that when decreasing its value, the current increases, and when increasing its value, the current decreases.	What would occur if the value of resistance approaches a very low value (almost zero), keeping the voltage without any modification? What would occur if the value if resistance approaches a very high value (almost infinity), keeping the voltage without any modification? Is it possible to establish a relationship of proportionality from the observations? If it were possible to modify the resistance and the voltage in the same proportion simultaneously, what behavior would the current have?
 The voltage is directly proportional to the product of the current and resistance.	Modify the size of the source's current (I) and observe what occurs with the voltage of the resistance. Note that when increasing the current, the voltage increases; instead, when decreasing the current, the value of the voltage decreases. Modify the size of resistance (R), and observe what occurs with the current. Note that when decreasing its value the voltage decreases, and when increasing its value the voltage increases.	What would occur with the voltage if the value of the resistance approaches a very low value (almost zero)? What would occur with the voltage if the value of the resistance approaches a very high value (almost infinity)? Is it possible to establish a proportionality relationship from the observations? If it were possible to modify the value of the resistance and the current in the same proportion simultaneously, what behavior would the voltage have?
 In serial connections, the higher the value of the resistor, the higher the voltage in the component.	Handle the variables of the circuit. Note that the sum of the sizes of the resistances' voltages is equal always to the source's voltage. Change the size of only one of the resistances. Note that by changing one of them, the voltages of both resistances change. In addition, the higher the resistance the higher its associated voltage.	What Conditions should the resistances fulfill for the circuit's current to be the minimum possible? If the value of one of the resistances tended to infinity, what would be the value of voltage associated to it? If there were a third resistance connected by following the pattern, what effects would it cause in the circuit? Is it possible to establish a relationship of proportionality from the observations?
 Distribution of the current in accordance with the value of resistances. In parallel connections, the higher the value of the resistor, the lower the current.	Handle the variables of the circuit. Note that the sum of the width of the currents is equal always to the width of the current that the source provides. Change the size of only one of the resistances. Note that by modifying only one of the voltages, the currents in the two resistances change. In addition, the higher the resistance, the much lower the associated current.	What Conditions should the resistances fulfill for the voltage in them to be the maximum possible? If the value of the resistances tended to infinity, what would be the value of voltage associated to it? If the value of one of the resistances tended to zero, what would be the value of voltage associated to it? If there were a third resistance connected by following the pattern, what effects would it cause in the circuit? Is it possible to establish a relationship of proportionality from the observations?

 Difference between the voltage in a component, or the voltage with respect to a reference.	Note that in this circuit the ground reference appears, and the nodes are marked with the letters “a” and “b”. The voltage of the “a” node with respect to ground (Va) appears in the top right corner. Handle the components of the circuit; note that always the voltage in Va is equal to the sum of the voltages associated to the variable resistances. Handle the components of the circuit; note that always the voltage in Va can be determined as the voltage of the source minus the voltage of the non-variable resistance.	Change the size of the variable resistances for them to be in their minimum value. Why are their voltages the same? Why, when changing the size of a variable resistance, do all the voltages in the circuit change? What sizes should the variable resistances have for the Va voltage to be half the size of the input voltage? If the ground were placed in the “b” point, what would be the Va voltage? If the ground were placed in the positive point of the voltage source, what would the voltage Va be?
 Principles of the dynamic response of the circuits. The change of the voltage in a capacitor is continuous. How the time of response depends on the value of the components.	Make changes in the input voltage; note that the voltage in the capacitor tends to reach the same size as the source’s voltage, but it takes some time in responding. This amount of time is called transient period. Note that when the resistance is low, the transitory period takes less time, whereas if the resistance is high, the transitory period is longer. When the transitory period finishes, it is said that the system is in a steady state. Note that in a steady state, the current tends to zero.	Why, in a steady state, does the variation of the resistance not generate any effect in the voltage of the capacitor? It is said that in a steady state, the capacitor behaves as open circuits if the power supply is constant. Does this circuit allow the verification of this statement? If one were asked to draw a graph of the behavior of all the variables in this circuit, what approximate image would one obtain? What considerations should be considered?

to the current circuit, as well as the credits. In the Figure 2, the user’s graphic interface is presented, even though, as a complementary alternative, the program offers the option to hide the menu and the tabs. This is done with the objective of allowing its use as a presentation directly in the classroom.

About the menu of circuit selection, each circuit is represented by an image that corresponds with its schematic diagram. It is not possible to see all the options of circuits at the same time, which is why there are options for the movement of the buttons.

The work area is composed of the schematic diagram of the circuit, the variables that are controllable by the user, and behavioral indicators. The controllable variables appear in red; they stand out because the corresponding letter contains an arrow that crosses it. Each variable is next to the component that it represents, whereas the rest of elements present various colors: In brown, the variables that are dependent on the circuit are presented. These variables cannot be changed by the user but depend on the dynamics of the system. In blue or violet, the currents associated to the branches of the circuit are presented. Finally, the interface includes the informative tabs, which are used with the objective of providing in-formation related to the current circuit. Three tabs are implemented: The first one presents information about the functioning of the circuit; it is expected that the behaviors that can be analyzed according to the schematic diagram become evident. The second tab presents questions related to the functioning of the circuit. The third tab presents the credits of the program.

3. Proposed Activities

This work includes two relevant stages in the work to reach the planned goals; on the one hand, a support of orientation, and on the other hand, discussion. The student and the instructor should follow the orientations and answer questions that guide the learning opportunities. Then, the instructor will debate the ideas of their students, and will help to focus on and conclude about the concepts.

In this software, various circuits that support the teaching process of key concepts in the study of the analysis of electric circuits were included. Particularly, those circuits that potentially could eliminate conceptual difficulties or erroneous ideas commonly identified by instructors were selected. The suggested activities are based on determined circuits, conditioned to be able to serve for specific educational purposes. Specifically, they are conditioned to strengthen the skill of obtaining the analysis of a circuit qualitatively; to put it another way, without using the formulae. To illustrate this statement, the following example is presented: In a voltage divider circuit, it is expected that students learn the associated formulae, and based on this, it is expected that apprentices can establish the voltages of the components. With this application, it is sought that students note that if they change the value of one of the resistors, all the voltages of components simultaneously change. Additionally, the higher the value of the resistor is, the higher the corresponding voltage.

In Table 1, a selection of basic circuits that appear in the software is presented. These circuits are a sample that represents the total of the implementation made in the software. The table presents the information of the key concept that is sought to be strengthened, the orientations that are provided to handle this tool, and finally, the discussion associated with questions to have some feed-back of the process and evaluate if the qualitative conceptualization is present.

4. Conclusions

Given that the pedagogical basis of the software is the paradigm or the pedagogical trend of constructivism, the inclusion of orientation and discussion activities become alternatives that link the student with aspects related to the cognitive, affective, and social realms, and that promote in this way the construction of explanations, and therefore, of knowledge. These activities allow the student to learn from his own practice, from the reflection about their actions, as well as in the participation and debate with the others' ideas.

It can be stated that the tool used as a support for the instructor allows the construction of explanations coming from qualitative experiences, involves the group, and emerges as a motivational element when eliminating some difficulties related to the laboratory work. The consolidated work approaches the process with which science history has shown that this kind of knowledge has been built, and moves away from memory processes and theories in the current instruction of science and technology.

This software was developed to have free distribution, and was programmed using Unity 3D. The use of this engine allows exporting the application to a wide variety of platforms, of which PC, Mac, and Linux with "Standalone" versions can be highlighted. Also, this tool can be exported to work as an Android or iOS application, or to work via Internet with browsers that support WebGL. This permits advantages in its distribution, and its application in different educational scenarios.

The tool presented here is part of a continuous process of reflection about the didactics of technology. It is not considered a final product; instead, it is part of a constantly discussed academic interest on the part of instructors of this field. Elements that are open to discussion include the conceptual improvements in the software use, and the selection of circuits that allow the instruction of key concepts, and that potentially, allow the elimination of certain conceptual difficulties or common erroneous ideas that are clearly identified.

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