Design and manufacture of a didactic tool through the use of 3D printing technology to teach the capacitor charging and discharging phenomenon

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Abstract. This paper reports the design and manufacture of an easy-to-use and accessible teaching system by using 3D printing as a tool for the teaching of the capacitor charging and discharging phenomenon. The didactic system developed, is structured in modules-built piece by piece with 3D printing technology. They are made in a relatively low-cost polymer that could facilitate both teachers and students to improve the teaching-learning processes. This didactic system is reliable, easy to use and low cost. As a way to improve the functionality, the built system is complemented by the use of a free access software and a simple generator of signals that allows to simulate a virtual oscilloscope. This is an additional strategy that would allow the didactic system to enrich the study of the phenomena and eliminate the use of high cost devices that generally limit the experimentation developed traditionally in the teaching of physics. The practical application and implementation of 3D printing technology can be incorporated into a wide variety university subjects in the development of experiments in circuit theory, electricity and magnetism, among others, for its advantages in facilitating the comprehension and assimilation of difficult theoretical concepts and the learning of the physical tangibility of the phenomena under study.

1. Introduction
Electromagnetism is an important physics area that seeks to understand the electrical and magnetic phenomena in nature. Therefore, its study is a necessity because it offers an important point of reference for the study of matter that allows incorporating essential elements in the study of the electrostatic, atomic and molecular interactions that occur in matter. In electromagnetism, it is possible to understand the behavior of electronic devices such as voltage sources, resistors, capacitors, transistors, among others; which are elements of great importance for teaching the theory of electrical circuits.

The development of experiments with electrical circuits in physics requires the use of electronic components that are usually simple ones, but when we have the specific components and equipment, these experiments are generally made with highly expensive and robust equipment. Otherwise the experiment could be complicated if we do not have the necessary equipment for the development of the experiment. In this sense, in educational institutions with low funding there is an evidenced fear in both students and teachers to develop this kind of experiments, since they see experimentation as a relatively difficult process and not as a mechanism that allows them to understand and secure their knowledge, due to the need to overcome different difficulties for the development of experiments.
In this sense, some works that have been reported various didactic strategies are discussed to facilitate and improve the teaching-learning process of electromagnetism courses [1-4], specifically in circuit theory, such as: Greca et al [5], classify the students according to the type of mental representation they used to solve situations of electricity and magnetism courses. Furio et al [6], reveal that the introductory concepts of fields and electric potential are prerequisites for acquiring a vision of the electromagnetic phenomena that are important to address the topics of direct current circuits and in general, of the electromagnetic theory. Varela et al [7], present a methodology based on the detection of preconcepts, the elaboration of the curriculum, the design of didactic materials and the evaluation of the concepts before and after developing the experiments using the didactic material. Angarita et al [8], develop a study that allows the incorporation of didactic material for the teaching of science and technology concepts in children of initial training schools. Angarita et al [9], use a computerized material as a tool for teaching basic electronics that facilitates the learning of the basic components of electronics.

In some other works, it has been possible to report the development of didactic material for the teaching in different areas of physics including the theory of electromagnetism [10], and in some cases, using different didactic strategies that allow the use of low-cost tools manufactured by students [11]. In particular, in the theory of circuits some local educational institutions that do not have enough resources to acquire laboratories specialized equipment, which has led to the search for new teaching strategies that allow the development of low-cost didactic materials. These new teaching tools that can be developed, must provide the same benefits as conventional equipment and elements, allowing students to obtain equally significant learning.

On the other hand, 3D printing is a new technology that allows the printing of pieces and assemblies of different shapes with different physical and mechanical properties and different types of materials. Currently, its main application is in the manufacture of prototype parts and finished products in the areas of engineering, architecture, medicine and in general the basic sciences. Due to its great application, 3D printers can also be very useful in education, because they are ideal in colleges and universities for the manufacture of prototypes, and particularly in the education-oriented programs, where they can have mainly two types of uses: the first, is related to the printing of the didactic material that the teacher uses as a complement to develop his own class and finally, the printing of prototype pieces that the students use for the development of the experiments.

In relation to the use of 3D printing technology or tool for the development of didactic material, there are some reported works: Solís et al [12], perform a review on the didactic use of 3D printers in Colombia as a tool for learning; Rúa et al [13], demonstrated that 3D printers are a low-cost tool that improves the learning process in the areas of engineering and design, and they consider that it is possible to generalize the tool to apply to other areas of interest, including the teaching of science.

In this work, we report the design and implementation of a didactic tool made by 3D printing technology used to teach the capacitor charging and discharging phenomenon. The didactic system is a modular system that has been designed and manufactured by using computer-aided design software CAD and was manufactured piece by piece using a 3D printer. The design facilitates the incorporation of banana plugs that allows the connection between different electronic components, such as resistors, capacitors, cables, sources, among others. As an additional tool, the didactic resource is complemented by the use of software of free access that allows the simulation of an oscilloscope and the incorporation of a simple signal generator to clearly identify the charge and discharge curves of the capacitor.

2. Method of design and procedure
One of the main difficulties of teaching in the area of physics is the transmission of knowledge through the written or spoken word. To solve this problem, some authors suggest the supporting on visual elements to enhance the understanding of the concept net that is being developed in a precise and simple way. In this sense, the manufacture of teaching materials and the development of
experiments for teaching constitute a valuable tool of supporting to the teacher that allows to improve the learning of the students.

According to this and taking into account the different difficulties presented for the development of experiments in physics, in this research, we decided to investigate about the difficulties of some of the traditional experiments that are carried out in the courses of electromagnetism and specifically about the difficulties that are originated for the limitation of the equipment used for the development of the experiments. Specifically, we have chosen the phenomenon of charging and discharging of a capacitor. Because, this is one of the classic experiments developed in electromagnetism courses, and at the same time, because it is an experiment where the physical tangibility of the phenomena under study is analyzed.

In this work it is possible to emphasize that the didactic system manufactured was designed by modules, piece by piece using computer-aided design software SolidWorks 2016 SP3.0. In the design it was possible to consider the electrical interconnections of each one of the electronic components that are part of the didactic system and at the same time it was possible to consider the external connections with power supplies, generator of signals, interfaces for connection to the computer, measuring instruments and in general with any other external device that can adapt to the system.

3. Experimental design
For the design of the didactic tool, we have used the printer XYZ printing da Vinci 1.0A, which is a commercial 3D printer that can support different types of materials including ABS polymer. The designing and manufacturing of the pieces facilitated the incorporation of banana plugs that allow the electrical connection between electronic components and external measuring devices. In Figure 1, the 3D design developed in CAD computer-aided design software is observed, while in Figure 2, the manufactured piece that contains each one of the components and electronic elements of the system is observed.

In order to put the teaching system into operation, we have chosen the experiment of charging and discharging of a capacitor and for this, we have proposed the simple circuit shown in Figure 3, which contains a resistor and a capacitor.

On the other hand, the circuit of Figure 3 shows the use of a signal generator, which was designed using the XR-2206. The diagram of Figure 4 shows the general design of the signal generator, which is a relatively simple circuit that allows to obtain square, rectangular and sinusoidal wave signals, and at the same time allows a sweep of frequencies in the range of 33 Hz -1.3 KHz. On the other hand, in order to observe the charge and discharge curves of the capacitor, we have used an open access software known as BIP Oscilloscope 3.0, which is a software that allows to use the computer as a virtual oscilloscope using the audio card of a computer as the input port.
In Figure 5, an image of the main interface of the software is observed, which allows the selection of the scales of Times/Div, trigger and Volt/Div.

In order to couple the square wave signal supplied by the signal generator to the computer, a signal conditioning circuit is required as a protection mechanism for the audio card. The implemented circuit for coupling the signal provided by the signal generator to the computer uses the LM324 component and its configuration is observed in Figure 6. The Figure 7 shows the charge and discharge curves of a capacitor observed in the virtual oscilloscope.
4. Result

For the realization of the capacitor charge and discharge experiment, we used a R=1 kΩ resistor, a C=4.7 μF capacitor and a signal generator in the square wave function with a maximum operating voltage of 9V. On the other hand, once obtained the 9 V of the square signal at the output of the signal generator, the circuit conditioning the signal reduces the voltage to 1V peak. The computer sound card acts as an analog / digital converter that acquires the signal through the microphone port and the information is interpreted by the oscilloscope BIP software, which graphs the charge and discharge curves. The graph obtained in the experiment corresponds to the equation $V_c = V_0(1 - e^{-t/RC})$, where it is observed that $e^{-t/RC}$ decreases with a time constant $\tau = RC$ that depends on the values of the resistors and the capacitance. The voltage increase is due to the decrease in the behavior of the exponential function. These results were obtained experimentally in the BIP oscilloscope software, which allows to export the graphics, as shown in Figure 7. In the Figure 8, the final assembly for the condenser charge and discharge experiment is observed using all the components manufactured and designed in the laboratory.

5. Conclusions

In this research, a didactic resource was designed and manufactured by using 3D printing technology to teach the phenomenon of charge and discharge of a capacitor. The system, as a didactic tool, can facilitate the teaching-learning processes at the moment of experimenting in the schools and universities in the courses of electromagnetism and theory of basic circuits because of its low cost. On the other hand, the system could be generalized to other types of more complex experiments with a larger number of electronic components and greater difficulty. In the same way, it is possible to think about the development of didactic material for other courses, including the comprehension and assimilation of difficult theoretical concepts and the learning of the physical tangibility of the phenomena under study.
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