

ICT-enhanced teaching of electrical circuits

Stavros G. Stavrinides
Computer Science Department
University of Thessaly
Greece
sgs@cs.uth.gr

Athanasios Taramopoulos
Secondary Education
General Lyceum of Nea Zichni
Nea Zichni, Greece
ttar@sch.gr

Euripides Hatzikraniotis¹, Dimitrios Psillos²
¹Physics Department, ²Department of Education
Aristotle University of Thessaloniki
Thessaloniki, Greece
evris@physics.auth.gr, psillos@eled.auth.gr

Abstract— Electricity-related concepts, such as electric current, voltage and resistance, are important concepts taught at all levels of education. However, teaching electric circuits poses many challenges for both the teacher and the students, mainly due to poor students' ability to visualize the basic concepts. In this work, we address this problem through an overview of ICT available aids and software for teaching electrical circuits.

Keywords—*science education; teaching circuit theory; simulations; virtual laboratories; modeling.*

I. INTRODUCTION

Electric circuits, seen as a central area of physics and science curricula at all levels of education, are taught at all three levels of education: basic, middle and higher education [1]. However, several studies point out that many students in science classes are having difficulties in understanding electricity-related concepts, such as the electric current, voltage or resistance. Hart outlined that teaching electric circuits (or electricity in general) poses many challenges for both the teacher and the students [2]. Not being able to clearly understand the topic, students often develop misconceptions [3], [4] which contribute to a limited performance on tests and consequently affect negatively the students' learning of further academic concepts [5].

Electricity's intangible nature causes many students, even those who have completed a physics course, to have incorrect ideas about it and about the behavior of electrical circuits. McDermott studied examination responses from groups of university students who had completed a course on introductory physics, including electrical circuits and Ohm's Law. The students were presented with an exam question about a simple DC circuit. Although the students had the necessary mathematical skills and had previously used Ohm's Law to solve more complex circuit problems, only 10-15% of them answered the question correctly [6]. McDermott found that many students failed because they held misconceptions (e.g. "current is used up by the bulbs in the circuit"), misunderstood concepts (e.g. equivalent resistance), used concepts incorrectly, or lacked a conceptual model that would enable them to make qualitative predictions about the behavior of circuits [7]

There are many reasons why these misconceptions emerge in class teaching. For example, one of the main reasons for misconceptions to occur, when teaching electricity, is the fact that students are not able to observe the actual flow of the electric charge. It is therefore difficult for the students to imagine the electric flow by merely watching a light bulb turning on when connected to a circuit. One of the main

reasons may be that for abstract concepts such as electricity, helpful teaching aids, which assist students to clearly visualize the phenomenon and grasp the concept, need to be presented along the theory [5]. Therefore, abstract concepts like the electric current, voltage, and resistance need appropriate use of *both* verbal analogies *and* physical models that will help students to visualize and comprehend the concept.

In this work, we address this problem (lack of adequate understanding in verbal-only representations), through an overview of ICT-available aids and software for teaching electric circuit theory. Thus, teaching of electric circuits, become ICT-enhanced.

II. OVERVIEW OF EDUCATIONAL SOFTWARE

Confucius' quotation "*I hear and I forget—I see and I remember—I do and I understand*", depicts the basics premise of the major contemporary approaches in education. Information and Communication Technologies (ICT) offer a wide hands-on activities range, which encourage learners to actively participate in the construction of knowledge. Today, there are a variety of flavors of ICT-enhanced aids to help students' active learning. These, include Simulations, Virtual Laboratories, Virtual Reality Laboratories, Real & Remote Laboratories, Modeling Software and more recently, dedicated software for *edutainment* i.e. "serious" gaming. All the above categories are available both as stand-alone applications, as well as web versions of the ICT-based educational software and they will be briefly discussed.

A. Simulations

Simulations help students to overcome the problem to understand different representations and translate them, thus they facilitate the development of the appropriate mental models [8]. In Fig. 1a a simple circuit with its current flow (little moving balls) appears. Other simulations may use different type of representations (e.g. graphs, and instruments' readings, toggle between schematic and realistic representation of the circuit – Fig. 1b), more or less realistic (Fig. 1c) or schematic (Fig. 1d) circuit pictures. Some of them are stand-alone (Fig. 1a) others are web-aware in the form of flash simulations (Fig. 1b) or applets (Fig. 1c). All simulations are actually hardcore coded to the phenomenon they depict.

They can be either parametric, or single-valued. Exceptions are *physlets* (*Physics applets*), which are scriptable applets [9]. The instructor can build his own simulation (applet) using JavaScript language making calls to a build-in jar-type library (Circuitsimulator4.jar).

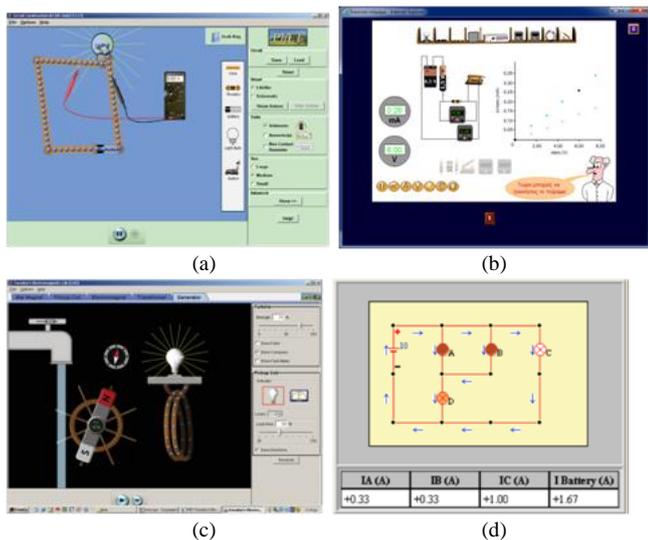


Fig. 1. Various flavors of simulations: (a) Ph.E.T. Circuit Construction Kit, (b) CD-Physics, (c) Faradays Electromagnetic Lab (Java applet), (d) Phylset..

B. Virtual laboratories

Virtual labs (VL) can be defined as a simulated interaction encompassing the contributions of technology, educational theory and individual human influences [10]. They provide environments in which learners can demonstrate a transfer of knowledge from theoretical to practical application [11].

In VLs the user can set up his own circuit, usually graphically, by drag and drop of electric elements. Contrary to simulations, the phenomenon is not hardcore coded; instead a generic set of equations is used (e.g. Kirchoff and Ohm laws), in time-slices for all nodes and branches to accurately simulate the circuit's time evolution. Some of the VLs use schematic representations of the circuit elements in a grid-like form (Fig. 2a), others uses more realistic representations (Fig. 2b). In some VLs, circuit elements are not arranged on a grid, but are connected by loose cables (Fig. 2c), while others use both types

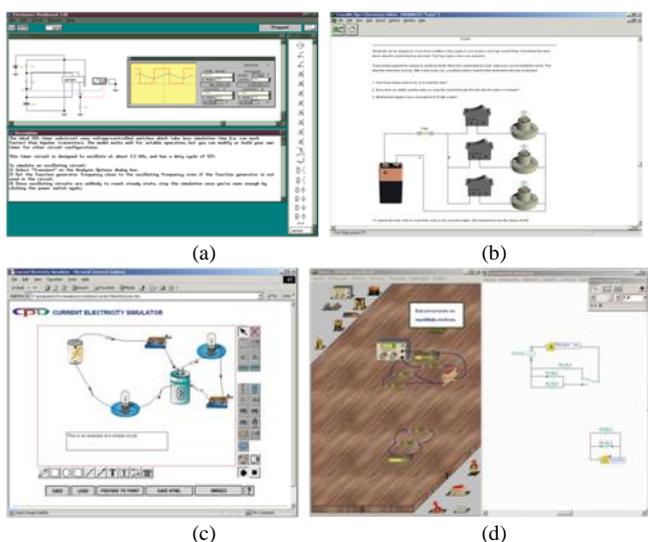


Fig. 2. Various types Virtual Laboratories (VLs): (a) Electronic Workbench, (b) Crocodile Clip, (c) CPU, (d) Edison.



Fig. 3. A Typical web-based Virtual Laboratory (web-VL [14]).

of representations (realistic, as well as, schematic) in parallel (Fig. 2d).

The web-variant of a VL is the web-based VL. Web-based VL emerged due to the extensive global adaptation of the World Wide Web and advances in network technology, even though the concept and methods of the collaborative learning, enhanced by computer technology, dates back to 1984 [12]. Today, web-VLs are becoming all the more accessible to many students at an unprecedented rate [13].

A typical web-based VL, for electric circuits is presented in Fig. 3. It uses realistic 3D representations of lab objects, model-space and it is highly consistent with the theory. It is written in Java language and functions as a java applet, allowing access from any browser through the World Wide Web. The user can directly manipulate the laboratory objects, compose arbitrary circuits and perform open inquiry and investigative activities. The virtual laboratory offers the choice of constructing analog or digital circuits.

C. Real & Remote Laboratories

Measurements in *Real Labs*, can be performed with the aid of a console, interfacing the computer to the real word circuit. Many experiments, from simple to more sophisticated ones may be performed, where real-time graphs are presented in the computer screen. For example, in Fig. 4a is depicted the output current-voltage measurements, across a flashlight bulb. The measurements were performed by applying a 2–10V voltage at different frequencies (10 and 100 mHz, 1, 10 and 100 Hz). The voltage across the bulb is recorded with Pasco Science Workshop™ 750 Interface and Science Workshop™ Version 2.2 software [15].

The web-variant of a *Real Lab*, is *Remote Lab* (RL), where the settings and the outputs are delivered through the web. RLs allow users to perform experiments and laboratory tasks over the Internet, without being near the actual equipment. In a traditional proximal laboratory (real lab), the user interacts directly with the equipment by performing physical actions

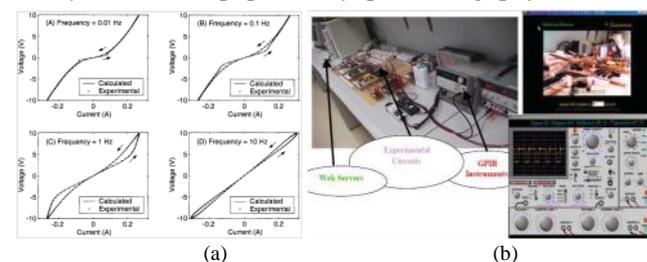


Fig. 4. Real and Remote Laboratories (a) graphs generated by a Real Lab [15], (b) remote Lab [16].

(e.g. manipulating with the hands, pressing buttons, turning knobs) and receiving sensory feedback (visual, audio and tactile). In a remote lab, this same interaction takes place at a distance with the assistance of the remote infrastructure. This is a new layer that lays between the user and the laboratory equipment, and is responsible for conveying user actions and receiving sensory information from the equipment (Fig. 4b).

D. Virtual Reality Laboratories & Serious Gaming Lab

Virtual Reality Labs (VRL) is a new trend and appear to be an extension of VLs. The goal of the VRL is to make laboratory environment as natural as possible, while maintain the characteristics of experimentation, as in VLs. One of the motivations for using naturalistic conditions is that the results have immediate applicability to the real world, with consequent applications on a variety of domains including neuropsychological and human-computer interactions. Some of the VRLs use sophisticated equipment (e.g. 3D-glasses), so that the user feels the augmented virtual reality. Others, use sophisticated programming and extended real 3D-graphics. A typical VRL is presented in Fig. 5a, and uses Java-3D to allow navigation in the lab space, rotation and zooming. The user may have a closer look to the measuring instruments, and different perspectives of the circuit he is building.

Using the technology of virtual reality with high quality graphics and a sound story though a challenging content, the new emerging trend in science software has appeared; the *serious gaming*. A serious game or applied game, is a game designed for a primary purpose other than pure entertainment. Serious games are simulations of real-world events or processes designed for the purpose of solving a problem. Although, serious games can be entertaining, their main purpose is to train or educate users, though it may have other purposes, such as marketing or advertisement. An example of serious gaming software is the “*E&E electrical endeavors*” on electrical circuits. The game can be typified as a simulation based game for individual use (not a role-playing game, where one plays with or against others). On the left part of Fig. 5b, the electrical circuit is shown as a closed circuit, providing an overview to the students which is much akin to the electrical schemes’ usually found in textbooks, while the “working screen” on the right, depicts voltage and current meters, as well as the way they should be connected more realistically. A pilot evaluation showed the game was attractive and entertaining for students [18].

E. Modeling software

Recently, using models has become one of the most effective methods for helping students to understand scientific

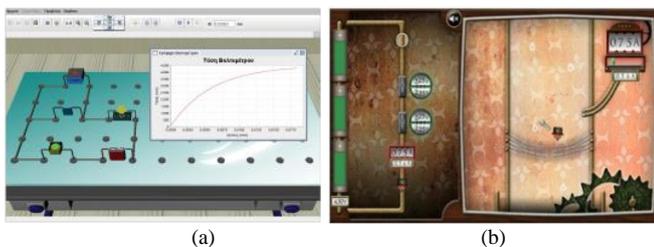


Fig. 5. (a) Virtual Reality Lab [17] and (b) Serious Gaming Lab (E&E electrical endeavors [18]).

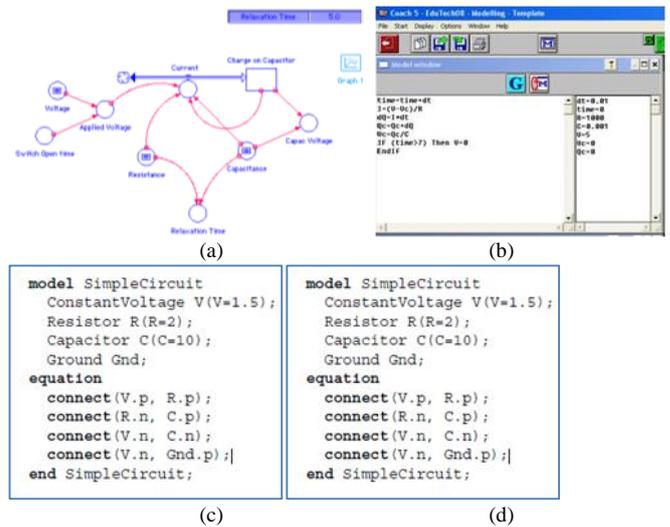


Fig. 6. Various modeling software: (a) Stella and (b) Coach for modeling the charge/discharge of a capacitor, (c) Modelica and (d) Physlets for building-up a circuit

concepts. A model is a simplified and formulated structure that explains an abstract property of a phenomenon or object in a convincing way.

There are various types and flavors of modeling software: Stella (Fig. 6a) uses a graphical representation of generic flows (e.g. $i=dQ/dt$), reservoirs (e.g. a capacitor), etc. to build-up the model. The basic idea is expressed graphically with storage and flow symbols. On the other hand, Coach (Fig. 6b) uses the mathematical (algorithmic) description. Both software systems translate the verbal description of the phenomenon (e.g. charging of the capacitor) into diagrams and equations creating a dynamic modeling. The output of such a software is typically a graph of the dynamic evolution of the system.

Other modeling software, uses text to describe the circuit (Fig. 6c, 6d) and build-in libraries, which take care of the circuit behavior. For example, a grid is set with the call *setGrid*, and objects are added *addObject* is the called function with parameters the type of object (battery, bulb, etc.), the value, the label, the starting grid row and column and the direction (Fig. 4d). The output of this type of modeling offers a visual (schematic) representation of the circuit, as well.

III. EFFECTIVENESS OF ICT-ENHANCED EDUCATION

Traditionally, educational curricula about electrical circuits have two components: (i) textbook-based instruction and (ii) practical, hands-on lessons. In textbooks, the subject matter is often approached from a factual and calculus-based angle. Students are presented with facts, definitions, and laws, and they are taught equations (e.g. based on Ohm’s Law, $I = V/R$) that can be used to solve standard circuit problems [19]. Therefore, textbooks and the exercises in the textbooks often emphasize procedural skill, which is “the ability to execute action sequences to solve problems” and the reproduction of facts and definitions.

These textbook-based lessons are often supplemented with practical lessons in which students can build electrical circuits and carry out measurements. These practical lessons are essential for developing skills and experience on working with real equipment and, through experimentation, a conceptual

understanding of the domain. However, practical lessons also have limitations that in general keep students from developing a proper conceptual understanding. For example, in practical lessons students tend to focus on making their circuits work rather than on trying to understand the causal relations between variables and outcomes [20]. Furthermore, when working with real circuits students must deal with all kinds of unexpected circumstances, like dim bulbs misinterpreted as unlit [21] and deviations from what they have learned in the textbook-based lessons. For example in reality, equipment (circuits, resistors, wires, batteries) is not ideal, consequently circuit measurements in show different outcomes, than those expected according only on the basis of formulas. Furthermore, students often do not engage in systematic experimentation and they rarely, if ever, link their hands-on activities with what they have learned in the textbook lessons [7].

Building or adjusting experimental setups with real equipment can be laborious and time-consuming. Advances in ICT technology and easy connectivity to high speed web, offers today a variety of teaching aids for enhanced active learning.

Simulations contain models that are designed to simulate systems, processes, or phenomena. Students can change the values of variables in the simulation (e.g. the resistance in a virtual electrical circuit) and observe the effects of those changes on other variables (e.g. voltage or current). The simulations allow students to conduct experiments and collect experimental data quickly and easily.

Virtual laboratories simulate real science laboratories on a computer screen, in a visual and functional manner, by exploiting modern multimedia technology and especially user interaction, immediate and realistic variable change, and equipment handling [22]. In a virtual lab, in contrast to a real lab, the setup can be easily set-up and changes to the configuration can be made quickly and effortlessly, allowing students to focus and to stay focused on their inquiry processes without delay or disruption.

Recently, the increasing use of virtual laboratories in Science Education and the finding that virtual manipulative can be as effective in teaching as real laboratory equipment [23], has stimulated a discussion of redefinition of their role. In a number of cases, results indicate that virtual laboratories may even outperform real laboratories [24], [25]. However, as Evagelou and Kotsis [26] remark in their literature review, these research studies are mainly focused on University students (60%) and seldom refer to primary school pupils (20%) or high school students (20%). Furthermore, of those referring to high school students none is in the field of electric circuits, which is especially suitable for a comparison between virtual and real environments since objects with similar properties can be used in both environments [16].

IV. CONCLUSIONS

Electrical theory related, basic concepts, such as electric current, voltage and resistance, are important concepts taught at all levels of education. However, teaching electric circuits poses many challenges for both the teacher and the students, due to poor students' ability to visualize the basic concepts. In this work, we present an overview of ICT-available aids and

software for teaching electrical circuits. A large number of research studies have shown that virtual laboratories, as educational and teaching environments, are not inferior to their real counterparts, with regard to conceptual understanding, as well as, designing experiments [16].

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