Enhancing Science Education: the Model-space and Web-based Virtual Electric Circuit Laboratories

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***Abstract*—This paper presents two virtual electric circuit laboratories designed and developed within the Science Education Cosmos-Evidence-Ideas framework. The virtual laboratories implement all necessary Physics laws in real time and possess highly desirable features for Science Education, such as photorealistic graphics, direct manipulation of objects, user friendliness and multiple measuring instruments. Most importantly they incorporate multiple visualizations of the experiments via the Model-space tool which facilitates the linking between the schematics (model) and the real appearance of an electric circuit. One of laboratories is web-based and can be utilized remotely offering teachers and students unique advantages in distance education. The pedagogical and didactical impact of these virtual electric circuit laboratories in real classroom conditions is also discussed.**

Keywords*—*science education; web-based virtual laboratories; electric circuits;

I. Introduction

Laboratory experimentation is considered to be a key factor in Science Education Through experimentation students can acquire a better and deeper understanding of physical phenomena and can develop a scientific way of thinking. However, it has been found that during hands-on experiments students often tend to spend most of their time on handling equipment setups and taking measurements thus limiting the effectiveness of hands-on experimentation [1], [2]. With the advance of Information and Communications Technology (ICT) virtual laboratories have emerged as powerful environments which can successfully support experimentation student activities. 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 [3].

A large number of research studies have been conducted to investigate the effectiveness in science teaching of virtual compared to real science laboratories. These studies mostly show that virtual laboratories, as educational environments, are not inferior to their real counterparts [4]-[7] with regard to conceptual understanding and experiment design, though there are also studies which favour one or another type of laboratory [8]-[10].

Modern virtual laboratory environments can be categorized into five groups with respect to their technical runtime characteristics and appearance [11]: Simulations, networked applet labs (Cyber Labs), Virtual Labs (VL), Virtual Reality Labs (VR Labs) and Remote Labs (robotic labs controlled over network). Simulations, Virtual Labs and Virtual Reality Labs are computer applications which, mainly for speed and security reasons, are executed at the user's local computer. This restricts their use inside the school premises and does not allow assignments of exploratory homework utilizing the virtual laboratory. Such activities can only be carried out with the use of Remote Labs or Cyber Labs. However, constructing a Remote Lab, or, building a java applet requires skills which are beyond those possessed by the average teacher. Thus, during teaching teachers are restricted to using applets available on the Internet, without being able to create their own or modify existing ones. These applets are simulations with usually poor graphics which study only a very narrow range of phenomena. The Open Learning and Laboratory Environment (OLLE) and the Web-based Virtual Labs, which are described in the next section, fills this gap by enabling the teacher to construct arbitrary setups and use them through the network. Moreover, these environments incorporate a number of additional features which can act as bridges between the theoretical models and physical reality.

The present study presents two virtual laboratory educational environments in electric circuits and reports on research conducted on their effectiveness in promoting conceptual evolution in the field of electric circuits, when utilized in teaching-by-inquiry interventions. The reason for choosing to incorporate the virtual laboratories in guided inquiry interventions is that research showed inquiry to be a powerful approach for involving students in active construction of new knowledge and enhancing students' conceptual understanding [12].

II. Description of the Virtual Laboratories

A. *OLLE and the exported Cyber Labs*

The Open Learning and Laboratory Environment (OLLE) is a multi-faceted virtual laboratory in the fields of Optics and Electricity developed in the Greek language [13], [14]. It is a micro-world environment, with realistic 3D representation of

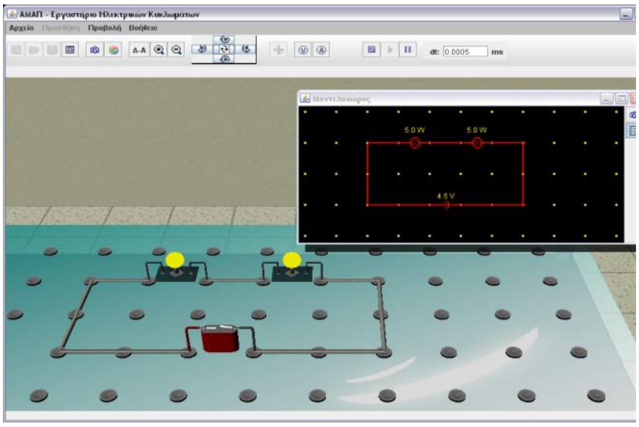

Fig. 1. The OLLE electric circuit laboratory and the Model-space

laboratory objects and appropriate functions for the simulation of electric circuits. It possesses a 3-dimensional environment with navigation and rotation capabilities, translation and zoom and allows users to construct a setup of their choice with fully and continuously functional virtual instruments. The electric circuits may contain DC batteries, AC sources, resistors, wires, switches, bulbs, fuses, capacitors, inductors, ammeters and voltmeters. The measuring instruments can also act as oscilloscopes plotting the intensity of the current or the voltage versus time with arbitrary time step, chosen by the user. The user is also allowed to control the time flow during the experiment, pausing the experiment or continuing at will.

Another innovative aspect of OLLE is the ability to store the electric circuit in a form of a fully functional java applet. Practically, this means that from each electric circuit a new simulation can be exported, which can be executed independently of OLLE, in the form of an applet. These Cyber Labs are therefore fully functional 2-dimensional symbolic multi-parametric representations of the virtual laboratory, highly consistent with the theory (Fig. 2), can be easily constructed by a user with no programming skills at all and can be utilized over the Internet.

B. *The electric circuit Web-based Virtual Lab*

This web-based Virtual Lab is also an open environment, in electric circuits, with realistic 3D representation of lab objects 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

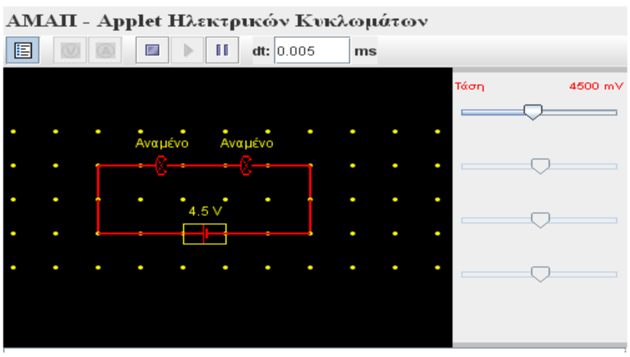

Fig. 2. The applet exported by OLLE for the circuit of Fig. 1

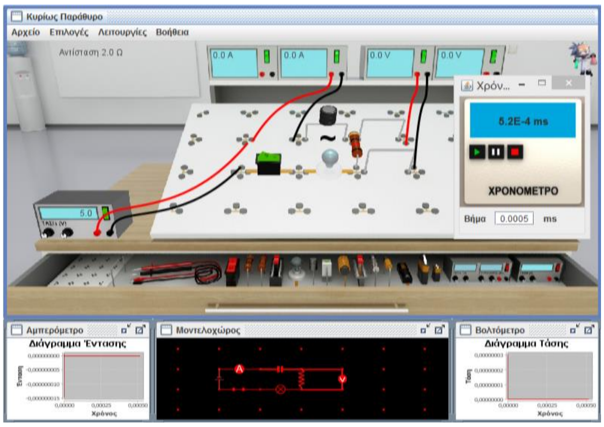

Fig. 3. The Web-based analog circuit Virtual Lab

and perform open inquiry and investigative activities. The virtual laboratory offers the choice of constructing either analog or digital electric circuits.

On the analog circuits' raster circuits can be constructed containing batteries, DC voltage sources, AC voltage sources, wires, resistors, switches, bulbs, fuses, capacitors, inductors, diodes, ammeters and voltmeters (Fig. 3). The measuring instruments' panels are shown in special places of the virtual laboratory window and depict the intensity of current vs time and voltage vs time graphs at the place where the measuring instruments are connected, thus functioning as oscilloscopes.

On the digital circuits' raster users can choose among realizations of various chips with logic gates, such as OR (74LS32), AND (74LS08), NOT (74LS04), NAND (74LS00) and NOR (74LS02). The user then explores the function of the single gates and arbitrary combinations of these gates with the use of switches and LEDs (Fig. 4).

C. *The Model-space tool*

Both virtual laboratory environments provide users with an additional space, the Model-space, which depicts a 2-dimensional symbolic representation of the real laboratory setup and displays in real time the schematics of the circuit constructed by the user (Fig. 1 and Fig. 3). The user can set-up electric circuits and execute experiments by direct manipulation of the objects and, at the same time, can observe the 2-

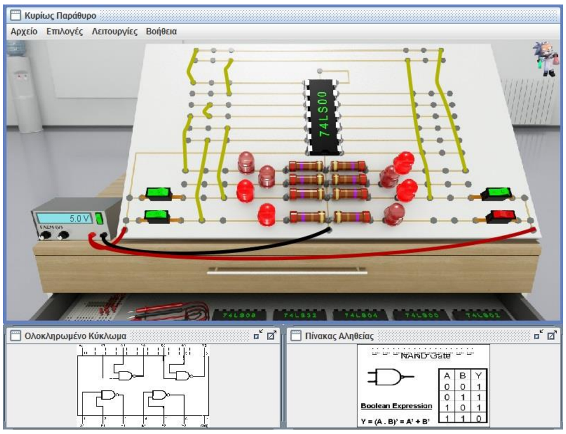

Fig. 4. The Web-based digital circuit Virtual Lab

dimensional Model-space symbolic representations of the virtual laboratory.

This innovative feature, allows therefore the presentation of multiple views of the phenomenon under study. The use of discrete worlds for representing the real and the symbolic entities is a main design strategy which was implemented during the development of these environments and has been presented in previous papers [15]-[18]. The dynamic link between the Model-space window and the window of the circuit in realistic form may act as a bridge so that a connection is established between virtual objects and scientific representations in students' mind. The user cannot act on this Model-space window except from capturing its content as a graphics file for further use. Research has shown that such affordances increase the students' conceptual evolution in complex situations [19], [20].

III. THE PEDAGOGICAL DESIGN FRAMEWORK

According to the literature [21], [22], there are three major categories of entities internal to scientific inquiry, namely "Cosmos", "Evidence" and "Ideas" (CEI). Material entities ('things' and 'raw data') realizing the phenomenon in the real world, belong to the "Cosmos". The data, which may be quantitative or qualitative as deemed by the experimenter, comprise the "Evidence". The "Ideas" consist of the concepts, theories, models, beliefs, etc. about the phenomenon under consideration. Both the scientific inquiry and the educational laboratory activities include connections between the three entities of the CEI framework.

Clearly, the described virtual laboratories follow this scheme. "Cosmos" is the virtual laboratory window, where the user (student) can set up experiments by direct manipulation of virtual objects and measurement instruments. Collected measurements such as instrument's readouts, graphs etc. form the "Evidence" dimension. The Model-space depicts the "Ideas" space in the CEI framework. It is connected to the experiment in "Cosmos" and creates relations between the real system and the abstract (model) which attempts to represent the system. The synchronous dynamically linked laboratory experiment with the model representation, helps students link the image of a "realistic world" (laboratory) with the scientific models and schematic representations, and (in addition) to observe the differences in the actual model, thus not to confuse the model with the material world, a common problem as outlined by many authors [23].

The CEI framework has been proven an efficient framework for the design of virtual laboratories and learning activities and helps students understand concepts, theories, models and representations of the material world [24].

IV. TEACHING WITH VIRTUAL LABORATORIES

OLLE is preloaded with a repository of activities, which engage students in predicting and observing phenomena, measuring and analyzing results and reporting findings. These activities consist of an electronic part and printable worksheets. The electronic part, which is embedded in the environment contains introductory information, questions provoking predictions on the outcome of various phenomena and exploratory applets. The student's answers are recorded in the printable worksheet, which guides the student through the steps of inquiry and the virtual experiment.

Similarly, the portal which hosts the Web-based virtual laboratory is planned as a repository of activities allowing access to both teachers and students. It contains printable worksheets guiding users through investigative inquiry-based activities. Having in mind the web-based nature of the virtual laboratory, the portal is structured to support open and distance education (non-typical education).

In both environments the design of the activities is based upon the constructivistic Predict-Observe-Explain-Expand scheme. All worksheets contain activities designed to focus on well-documented common misconceptions among students on electric circuits. This is achieved by the construction of various electric circuits and the study of their functionality (or lack of functionality).

In this way, these virtual laboratories are complete environments which guide students through all the steps of science investigation and can be incorporated in science teaching in a similar manner to their real counterparts. Several research studies have been conducted to investigate the effectiveness of these virtual laboratories.

Taramopoulos *et al* [18] have compared the learning outcomes in high school students when they are subjected to a teaching-by-inquiry intervention in a real and in the virtual laboratory environment OLLE with various affordances. Their findings indicate a similar conceptual improvement for all groups showing that the virtual laboratory environment can be effective in science teaching.

Taramopoulos and Psillos [20] have also investigated the impact of the Model-space tool in the development of science understanding in the field of electric circuits. They show that virtual environments utilizing dynamically linked concrete and abstract representations of objects may provide the necessary scaffolds for students to raise their level of understanding of phenomena with high degree of complexity when properly incorporated in teaching. This result is in line with the result reported by Olympiou *et al* [19] who conducted a similar study with OLLE in the field of optics.

These findings indicate that virtual environments when used in investigative activities may be effective in supporting students' conceptual evolution when students' are faced with both simple and complex phenomena in electric circuits. In simple phenomena, such as studying the intensity of the current in circuits with a battery and up to two more elements, concrete representations of objects in the virtual laboratory seem to suffice for supporting conceptual improvement.

However, when complex phenomena are studied, such as the intensity of the current in circuits with a battery and more than two other elements, or the time needed for a battery in a circuit to be depleted of its stored energy, the presence of both concrete and abstract representations of objects functioning based on the related scientific model seems to raise the students' comprehension beyond what is achieved by the presence of concrete representations of objects alone. One explanation could be attributed to the fact that the simultaneous presence of functional interconnected concrete and abstract representations of objects may help students develop the ability to create stronger links between representations of the required knowledge and to use effectively the most suitable representation whenever needed. This may result in the construction of a higher quality mental model by the student and thus facilitate a deeper understanding of the domain of electric circuits.

In conclusion, virtual laboratories designed under efficient pedagogical frameworks, such as OLLE and the Web-based Laboratories presented in this paper, when properly incorporated in science teaching may lead to enhanced conceptual evolution of the students in the field of electric circuits.

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