Web-based Virtual Labs

A Cosmos – Evidence – Ideas as a Design Framework Leading to Good Practice

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Abstract: This paper presents three novel open, web-based, virtual laboratories for Physics. The labs are open, meaning they embody a complete Physics micro-world that implements all necessary Physics laws in algorithmic format. They run in real time and are deployed as Java applets, in order to be accessible via the World Wide Web, with minimum requirements on the client side. Additionally, the labs present a number of features, highly desirable for virtual labs, such as photorealistic graphics, direct manipulation, user friendliness, multiple visualizations of the experiments and the corresponding phenomena and multiple measuring instruments. Finally we present the main design principles on which the development of the labs were based and we propose good practices that can help the acceptance from the science teachers' community and the more effective way of implementation into the class situation.

1 INTRODUCTION

Virtual laboratories (VL), simulate in visual and functional ways the classical science laboratory on the screen of a computer, the dynamics, provided by the modern multimedia technology, such as the interactivity, the direct manipulation of objects and parameters, the synchronized coupling of multiple representations (Kocijiancic and O´Sullivan, 2004, Hatzikraniotis et al, 2007). As a result, new possibilities and prospects, beyond the limits of classical laboratory, are introduced which create a technologically enriched environment potentially facilitating students' active engagement in scientific inquiry (Zacharia, 2005, Hennessy et al, 2007, Rutten et al, 2012, de Jong et al, 2013).

The effectiveness of VL in Science Teaching has been the subject of many research papers. Some have suggested that the study with the help of computer and multimedia applications can exceed, to some extend, the technical and instructive restrictions of classical hands-on laboratory in science teaching (Sassi, 2001, Petridou, 2005) while others have suggested that these applications have been effective in science teaching (Klahr et al, 2007) or that they promote the conceptual understanding in various aspects e.g. they can eliminate the handicap of the slow development of thermal interactions, and allow experimenting in "extreme" conditions with easy manipulation of variables (Hatzikraniotis et al, 2010). Martinez et al (2011) mentioned that "their use fosters conceptual development and change and helps students to comprehend many physical phenomena in different areas of study, such as mechanics, optics or even the entire science curriculum". Other studies show that combining them with a proportional number of hands-on experiments seems to be necessary for students' development of all dimensions of their experiment design skills. Although many researchers have found that groups of pupils who have worked with computer simulations make greater strides in learning, others have found that the benefits of learning through simulations are ambiguous (Ma and Nickerson, 2006, Trundle and Bell, 2010, Martinez et al, 2011)

According to Harms, modern virtual laboratory environments can be categorized into five groups: Simulations, networked applet labs (Cyber Labs), Virtual Labs, Virtual Reality Labs (VR Labs) and Remote Labs (Harms, 2000). Simulations, Virtual

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Labs and Virtual Reality Labs are computer applications that, mainly for speed and security reasons, are executed at the user's local computer, which restricts their use inside the school premises.

The solution, for using a VL beyond the school-class would be the Cyber-labs, web-based VLs. Today, they are in the form of java applets. Obviously, building a java applet requires skills which are beyond those possessed by the average teacher. Thus, during teaching, teachers may use applets available on the Internet, without being able to create their own or modify existing ones. Even though there are existing platforms for creating applets without requiring extensive knowledge of Java language, like Physlets scriptable applets (Christian, 2005), or Easy Java Simulations (Esquembre, 2004), teachers opt not to use them, since training is required on how to use them.

Furthermore, in ready-made applets, there seems to be a trade-off between the broadness in phenomena and the realism in the representations. It seems that the broader range of physical phenomena a lab can present, according to the degrees of freedom a teacher is given to construct his own experiment, the less realistic is the representation used, as for example the Java applets on Physics (Fendt, 2008). On the other hand, when the aim is photorealistic appearance and the direct manipulation, the outcome is rather ready-to-run experiments, where one can remotely perform only a limited set of specific operations (e.g. experiments in *www.vlab.co.in* as described in Pulijala et al, 2013). It seems lucking the fully operational environments for experimentation, where the user can set up his own experiment (even if it is not the correct one), run it and collect data for processing.

Our team has developed web-based VLs, which aim to fill this gap by enabling the teacher-user, as well as the student-user to setup his own experiment, with realistic representation of a real lab, and direct manipulation of objects (Hatzikraniotis et al, 2007, Lefkos et al, 2009, Lefkos et al, 2011, Taramopoulos et al, 2011)

Designing a VL (stand alone or web-based) is shaped by scientific (in the science education context), and institutional/educational factors. Thus, specific teaching–learning activities that students perform with this lab, as for example the ways and possibilities of linking theoretical entities and the material world (which lie at the heart of inquiry), are also affected by the designer's view of scientific inquiry. Science consists of representations of the material world but, at the same time, it contains methods of intervention in the material world especially at a laboratory level, where scientists explore the agreement of the experimental data with the underlying theories. This interventional practice in the laboratory is part of scientific tradition and a particular feature of the internal logic of laboratory science, which allows interaction of material entities with theoretical models. Hacking (1995), considered at first the actual laboratory science activities practiced by scientists and then, by working upwards, he attempted to generalize and produce patterns of scientific practice, which include three categories: namely, Cosmos– Evidence–Ideas (CEI). To the best of our knowledge, CEI framework was employed only in the analysis and epistemological modeling of teaching–learning (didactical) activities (Psillos, et al, 2004). In this paper, we argue that the CEI can also be an efficient framework for the design of web-VLs and the corresponding portal which will host them. As example, we introduce the recently developed web-VLs, with realistic representation of a real lab, a great feeling of direct manipulation of objects and parameters and the affordance to set up experiments and to manipulate them from a distance, through the World Wide Web.

2 THE VIRTUAL LABS

The web-VLs are 3 independent micro-world environments, in optics, heat and electricity, with realistic 3D representation of lab objects and appropriate functions for the simulation of relevant phenomena. The direct manipulation of the objects allows the user to compose experimental settings and fosters open inquiry activities and what-if investigations.

An innovative feature of the Labs is the existence of parallel components, which present 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 followed during the development of these environments and have been presented in previous papers (Hatzikraniotis et al, 2007, Lefkos et al, 2009, Lefkos et al, 2011, Taramopoulos et al, 2011). One component, the "Cosmos" window, is a virtual laboratory, which represents, with visual and functional reality, the phenomena and one other component, the "Model" window, which shows the symbolic representation of the experimental setup, is dynamically linked to the actual "labspace" and simulates the experimental setup in real time on the base of valid theoretical models. Each action on the bench of the "Cosmos" is reflected in real-time in this "Model" so that a link is potentially established between virtual objects and scientific representations in students' mind. The user cannot act on this 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 (Olympiou et al. 2012).

i The Optics Virtual Lab

A real world's optics bench consists of a series of objects, light sources and instruments (fig.1) by the help of which one can compose such settings that will allow him to study optical phenomena. The user can set up an experiment containing various optical objects (lenses, mirrors, prisms) of known or unknown characteristics (e.g. focal length), various light sources (laser beam, spot light of different colors) and various non transparent objects for the study of focal length, magnitude, shadow formation, color composition, image formation, using various apparatuses as an optical disk, a ruler, a photometer etc.

Finally, the Optics VL includes four discrete worlds: the VL bench which visualizes the reality, the model-world, which represents in real-time the phenomena taking place on the bench, the image formed at the screen and the graph of brightness. Objects can be manipulated only on the VL bench while in the model world and on the screen only measures can be taken.

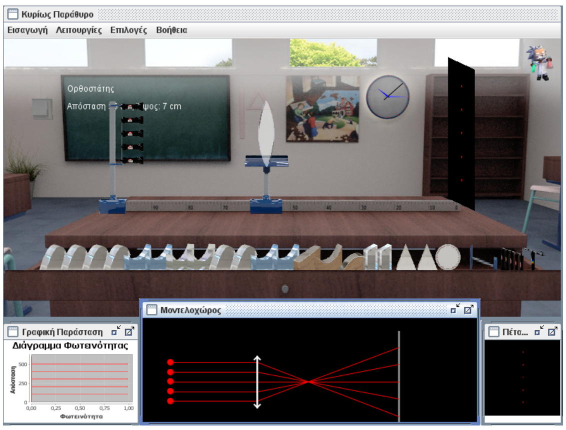

Figure 1: The Optics VL: Study of focal length of a biconvex lens.

ii The Heat Virtual Lab

This VL environment consists of the main bench where users can quickly and easily set-up and execute experiments by direct manipulation of the objects which include various beakers and thermometers, two heat sources, some liquids (water, milk, oil), soluble substances (salt, sugar) and some solid cubes made from iron, lead or gold (fig.2). There is also a heating chamber, a sink with faucet, a boiler, a thermostat and a chronometer with the affordance of time acceleration. Users can observe the results in multiple representations like graphs of temperature and heat exchange vs. time and the volume change vs. time.

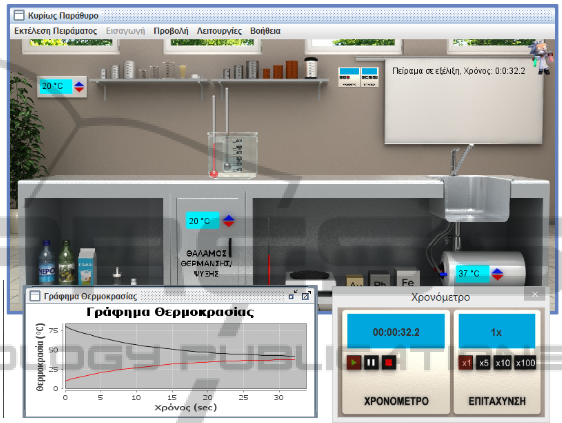

Figure 2: The Heat VL: Study of thermal interaction of two quantities water with different initial temperature.

iii The Electricity Virtual Lab

In this VL environment one can construct analogical or logical circuits by choosing among two rasters.

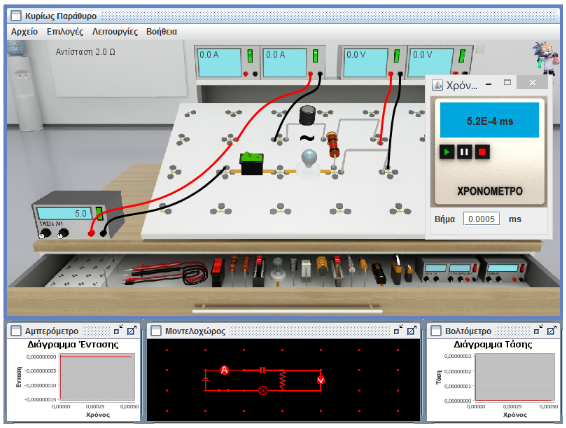

Figure 3: The Electricity VL: Study of a simple circuit.

The analog circuits' raster provides users with an additional space in the virtual lab, 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.3). There are various objects (batteries, resistors, cables, switches, potentiometers, lamps, capacitors, coils, diodes) which can be placed upon the raster and measuring devices (ammeters, voltmeters).The user can set-up and execute experiments by direct manipulation of the objects and, at the same time, can observe the 2-dimensional model-space symbolic representations of the virtual laboratory. Two diagrams: I(A)-t(s) and V(V)-t(s) are also available to the user for studying the time evolution of electrical phenomena.

By choosing the raster for digital circuits the user can study integrated circuits with logic gates AND, OR, NOT, XOR, NAND or NOR and the truth table of various combinations.

3 CEI AS A GOOD PRACTICE

In line with Hacking (1995), there are three major categories of entities internal to scientific inquiry, namely "cosmos" - "evidence" - "ideas" (CEI). Material entities ('things' and 'raw data') realizing the phenomenon in the real world, which we call as "Cosmos". "Evidence", which accounts for assessed, analyzed, reduced, etc., quantitative or qualitative data as considered appropriate by the experimenter; and "Ideas" (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 web-VLs follow this scheme. "Cosmos" is the virtual lab 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 (in separate graph-windows), etc. form the "Evidence" space. "Model space" in web-based VLs, is interconnected with the experiment in "Cosmos" and builds the correspondences between the real system and the abstract (model) which attempts to represent the system. The synchronous interconnected imaging of the 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 equate the model with the material world, a common problem as outlined by many authors (Vreman, 2004). "Model space" depicts the "Ideas" space in the CEI framework.

The portal for hosting the web-based VLs, currently under construction, is planned as a repository of activities. It may be accessed both by teachers and students. Having in mind the web-based nature of the VLs, the portal is structured based upon conditions and practices for open and distance education, therefore no typical (in-class) education.

The repositories contain folders with topics, also structured based on the CEI framework. In the "Cosmos" sub-folder, besides the web-based VLs, we intend to include, ready to run experiments. In the "Evidence" sub-folder, the activities, with hints for a more or less systematic processing of raw data; data representations, classification according to chosen criteria, comparison with other data, etc. Finally, in the "Ideas" sub-folder will be included specific theoretical issues, models or concepts, as well as methodological entities that gain a certain meaning in a theoretical framework, which can be a question or a hypothesis. We also include implicit views (i.e. views of reality, causality, relation between the subject of the knowledge and the external world) that, although not straightforwardly stated, may strongly influence the construction of scientific knowledge.

As an example, on how student activities are structured in the portal, we can mention the following inquiry-based problem. *"We have 3 cups made from different materials, a plastic-cup, e metallic-cup and a glass-cup. In which of the three should a hot chocolate better served?"* (Hatzikraniotis et al, 2010). There is a short description of the problem, and the aims of the activity. Then, in the "Cosmos" sub-folder are a number of ready-to-run experimental set ups. Each experiment is accompanied with a short description, the particular objective and instructions for use. Students may run the experiments, assisted by activity-sheets, guided to their observations, collect data and the suggested processing of raw data, data representations, comparison with other data, etc are pointed-out. These are found in the "collecting evidence" sub-folder. Finally in the "theory and believes" sub-folder (ie. the ideas sub-folder) are found documents of the underlying theory, explanation of the model-space window, students' beliefs and alternative ideas and a questionnaire for student self-assessment.

4 CONCLUSIONS

In conclusion, we argue that the Cosmos-Evidence-Ideas (CEI) can be proven as an efficient framework for the design of web-VLs and the corresponding portal to host them. This framework, we believe helps students to understand concepts, theories, models and representations of the material world, as well as their selection and application criteria in the social and physical environment (Bybee and Champagne, 2000).

Questions regarding the implementation of the web-VLs, either within the curricula or as an open-distance learning framework would be interesting to be investigated furthermore, in future work:

- how do science teachers adopt the web-VLs in everyday practice?
- how are students accessing and performing the VL experiments?
- which open and distance learning features need to be further adopted for a better implementation to above mentioned target groups?

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