OptiLab: DESIGN AND DEVELOPMENT OF AN INTEGRATED VIRTUAL LABORATORY FOR TEACHING OPTICS

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ABSTRACT
The international research and experience have proved that the approach of studying subjects with the help of computer and multimedia applications can exceed, to one degree, technical and instructive restrictions of classic school Science laboratories. The "virtual laboratories" which simulate, by means of visual and functional entities, physical phenomena or experiments in the screen of computer, develop the dynamics that provide the modern multimedia technology. Basic characteristic is the technique of interaction, the direct manipulation of objects and parameters and the ability of presenting interconnected multiple representations of the phenomena under study. As result, beyond the support of classic laboratorial approaches, new possibilities and prospects are introduced that extend the limits of methods of classic laboratory and create a technologically enriched environment in which the active and exploratory learning is facilitated. In this work, we present the design and development of a Visual Lab in the field of Optics. The laboratory is developed in Java3D and covers the fields of Geometric and Wave Optics. A unique feature of the lab is the co-existence of a “model space” which runs along with the actual “lab-space” (the “Cosmos”) and which presents a model of the experimental setup in real time.

KEYWORDS
Virtual Science Laboratory, Optics, Representations

INTRODUCTION

In the classical hands on science laboratory, the activities of students are usually focused in the handling of the objects of an experimental setup along with the measuring instruments. However research shows that the procedures of scientific inquiry are underestimated in favor or manipulations so that a gap is eventually developed in students’ minds that fail to link phenomena with the corresponding scientific theory or models. Also, an endogenous characteristic of the classical hands-on science laboratory is the limited capability of creating dynamic situations, via which the flexible combination of many or all parameters is rendered possible, so that the students can investigate several factors that influence the phenomena (Psillos et al, 2002).

The international experience and research have proved 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). In virtual laboratories, which 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, may be unfolded. 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 (Hake 1998, Huppert 2002, Zacharia 2005, Hennessy 2007).

More specifically, the characteristics of concepts and phenomena in the field of Optics introduce special requirements on the design of virtual environments, more restrictive from the requirements in other fields of Physics. Usually, in representing the entities of visual environments in fields other than Optics the software developers use visualizations and optical tricks that deviate from the real picture. The symbols used are explicitly explained to the user as a choice of a model so that he/she can comprehend the representations and connect them with the visualized concepts or processes. A typical example comes from the area of electric circuits as shown in Figure 1. In the following diagram we recognize the widely used symbols of a battery, the wires and the resistors. Even though the specific symbols have none visual resemblance with the real objects, they can help the observer to comprehend what it represents.

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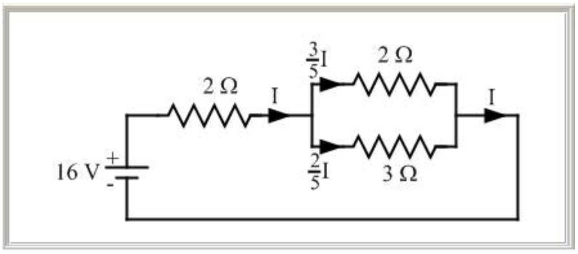

Figure 1. Symbolic representations for electric circuits

However, in Optics, which studies the light and visualizations, the representational metaphors and the object of representation coincide. Thus, only minor differences are allowed between the simulated phenomenon and its visual representation. For example, in the study of the path of a light beam through various optical means, an important issue is the topography of the observer. For example, the user, as an external observer of the visual representation of an optical laboratory setting on the screen of the computer, “cannot see” the light beams and the “virtual images” since he is not in the course of light rays.

Moreover, in the school books the representations of optical phenomena use a hybrid environment, which accommodates real objects of the world and in the same picture, models of Optics using virtual entities such as light rays and images as it is shown in Figure 2.

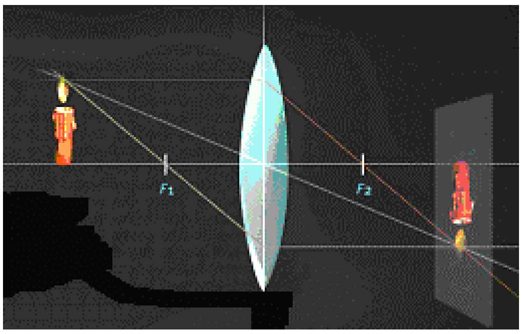

Figure 2. Hybrid representation of world and models

In the same time most existing software in the field of Optics use the same hybrid representational techniques. We consider that such design choices may contribute to students’ misunderstandings with regard to the nature of light and the phenomena of optics (McDermott et al, 2001; Buty et al, 2004; Mihas, 2005).

Our basic design strategy focuses on putting apart the different worlds to two discrete but matched environments. One environment, the “Cosmos” window, is a virtual laboratory, which represents, with visual and functional reality, the optical phenomena and one other environment, the “Model” window, which brings on the screen the symbolic representation of the setting, runs along with the actual “lab-space” and simulates the experimental setup in real time on the base of valid optical models. In this work, we present the design and development of the virtual Lab and the attached model world. The software is developed in Java3D and covers areas of Geometric and Wave Optics. To the best of our knowledge, this is the first time that Java3D is used to develop a virtual lab on Optics.

THE OptiLab COMPONENTS

The OptiLab software is a micro-world environment with realistic 3D representation of optic’s lab objects and appropriate functions for the simulation of Geometric and Wave Optics phenomena. The direct manipulation of the objects allows the user to compose optics experimental settings and fosters open inquiry activities and what-if investigations.

Innovative feature of the OptiLab is the existence of parallel components, which presents multiple views of the phenomenon under study. In typical textbook figures as well as in typical optics simulations, a hybrid model concerning the objects, the light beams and the images produced follows the visualization of the phenomena. The reader of the book or the user of the computer screen acts also as the observer of the phenomena. He can “see” both “the real objects” like a mirror or a lens and he can also “see”, together in the same picture, the symbolic objects like the light rays and the virtual images.

The use of discrete worlds for representing the real and the symbolic entities is a main design strategy followed during the development of the software presented in this paper. The Optics Virtual bench is the world, which visualizes the reality. A matched model-world represents in real-time the phenomena taken place on the bench. The parametric study of the model-world is further carried out in a third window, the applet window.

Each frame in the following Figure 3 represents a co-existing window, which can be opened separately as a different component of the same environment.

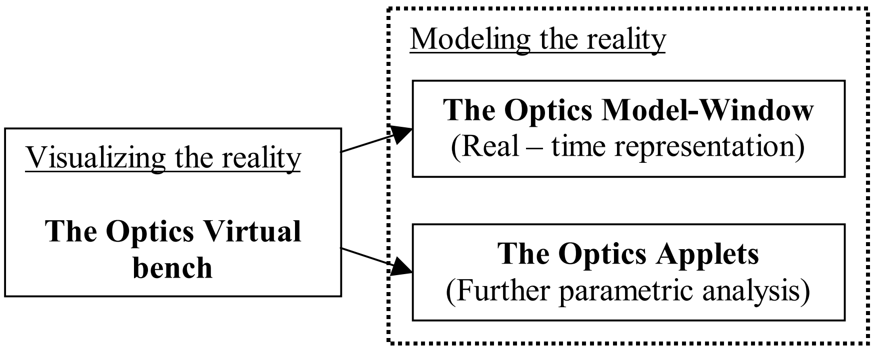

Figure 3. The OptiLab Components

VISUALIZING THE REALITY

A real world’s optics bench consists of a series of objects, light sources and instruments by the help of which one can compose such settings that will allow him to study optical phenomena. A virtual optics bench should therefore be similarly equipped and similarly used. In this frame, we developed the OptiLab for a virtual study of real optics phenomena. At the next figure of the Geometric Optics bench (Figure 4 and 5), we distinguish the following parts:

- The **OPTICAL ROD** along the bench, over which one can place and move optical objects. The rod is calibrated in “mm” for measuring the exact position of the objects
- The stand of the 5 Laser **LIGHT SOURCES**, at the left side of the rod. Each laser source can be activated independently and cad can be rotated at any angle. By this way the user can form any pattern of light beam (single beam, parallel, converging, etc.)

- The **OPTICAL DISK** for attaching optical objects and studying their affect at the path of the light. One or more disks can be used for attaching multiple objects selected from a list of flat or curved mirrors, converging or diverging thin or real lenses and other transparent objects. The disk can be rotated, moved along the rod and trimmed according to its height.
- The **MONITOR SCREEN** for the projection of the trace of the laser beams. The window which is activated by selecting the “monitor icon”, presents a detailed image of the screen.

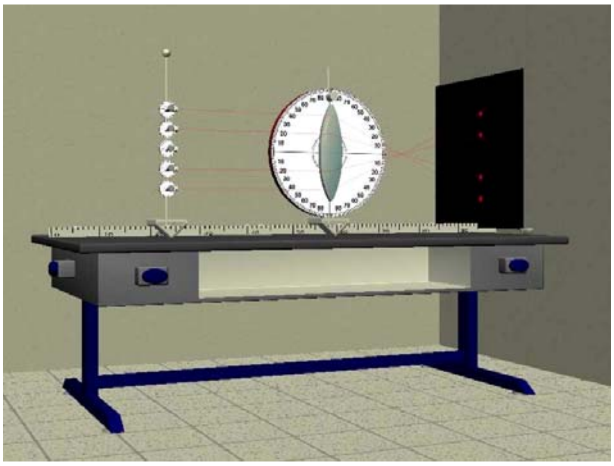

Figure 4. The Geometric Optics bench

A Geometrical Optics experimental setting is composed on the Geometrical Optics bench by selecting the desired optical objects and by aligning them in the appropriate position on the optical rod. After activating the light source or sources, the path of the light is visualized on the computer screen and in the same time on the monitor screen. The path of the light is formed in real-time in relation to the position to which the optical objects may be dragged.

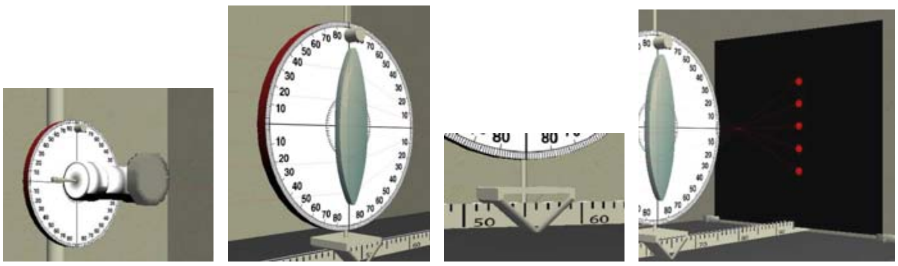

Figure 5. Details of the optics bench

Typical experiments worked out by the OptiLab are those found in science school textbooks. They allow the study of reflection and refraction laws (Figure 4), the estimation of the focal length, total internal reflection, Snell’s law etc. Furthermore, compound optical settings can be composed and studied for the comprehension of the physical effect of each optical object and running open inquiry activities. The Figure 6 shows the result of one converging lens, one diverging lens and one inclined flat mirror in the path of five parallel beams.

Distance and angle measurements are taken using the ruler of the optical rod, the protractor of the optical disk and the protractor of each laser’s base. External ruler and protractor instruments are also available so that the user can measure any distance and angle on the bench. Their icons on the menu bar activate the instruments.

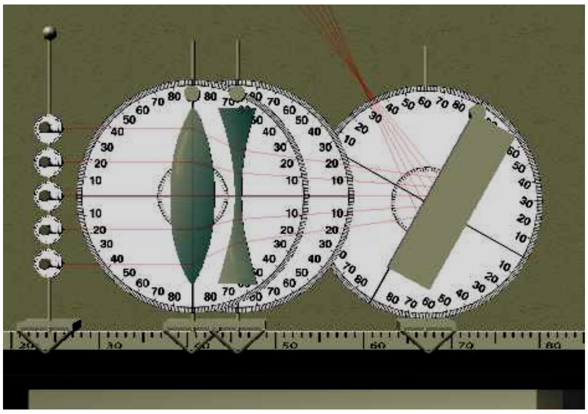

Figure 6. A complex Optical setting

MODELLING THE REALITY

Simultaneously with setting the objects up in the bench and running the experiments, a Model-Window presents a simplified schematic representation of the same experiment. Each action on the bench 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 has no effect on this window except the ability to capture its content as a graphics file for further use.

Each experimental setting can be saved as a lab file for further analysis. It can also be saved as an applet file, which can be loaded by a web browser. The OptiLab Applets present the symbolic representation of the virtual setting and allows the parametric investigation of the source experiment from where it derives.

At any applet, the user can select an object and move it by dragging it around the window. The selected object's parameters and their values are presented at the bottom of the screen (Figure 7), where the user can modify its value and witness the result of his action.

Figure 7. Parameters of a selected object

A WORKING CASE

Based on the descriptive schema of figure 1 we present the components of the OptiLab concerning a specific case, for example that of light reflection on a flat mirror. In the following Figure 8 we observe that 3 Laser beams, which aim towards a flat mirror and reflect on it at a specific angle, compose the Virtual Lab. The 4th laser has been turned off; but it can still be turned on by a click on the red switch. The 5th beam aims outside the mirror, but the Optical Disk stand can be, at any time, moved downwards in order to meat this beam.
Note that the setting has been slightly rotated in such a view, that the reflection on the mirror's surface can be seen. The bench can be rotated at any desired angle and zoomed-in at a close distance, for focusing attention to specific details.

At the same time the user can open the Model Window and observe, in real-time, the symbolic representation of the same setting. Every action on the bench reflects on the Model Window, so that the user may get a simplified and clearer view in two dimensions and a synchronized dynamic connection between the two alternative representations the virtual and the symbolic. The Model-Window of the example shows the 3 beams reflected on the mirror and the one beam projected on the monitor-screen. Saving the project as an applet and later loading it with a browser, one can observe the following:

The exemplary setting presents a flat mirror and 3 beams reflecting on it. The 4th laser has been turned off, it can though be turned on by a double click on the red point. The 5th beam aims outside the mirror, but it can be drugged at any place in the window. Note that the user has selected the protractor and the ruler for taking measurements. He has also selected the appearance of the small blue lines, which are the vertical lines at the point of reflection, so that the incident and reflection angles can be measured.

It becomes clear that the studying of a phenomenon, like the one presented above with the use of all the components of the OptiLab, may help students to a multiple-approached comprehension of Optics.

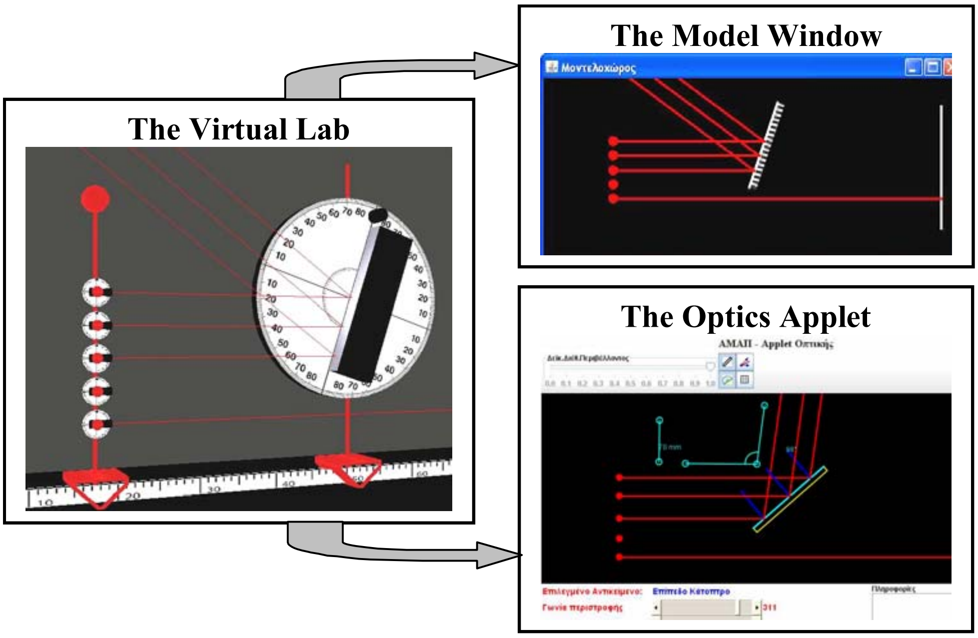

Figure 8. Multiple study of reflection

CONCLUSIONS

In this work, we present the design and development of a Virtual Lab in the field of Optics. The laboratory is developed in Java3D and covers the fields from geometric Optics to Wave Optics. A unique feature of the lab is the co-existence of a “model space” which runs along with the actual “lab-space” (the “Cosmos”) and simulates the experimental setup in real time. The software is under development and is intended to be used with upper elementary and secondary education students. The accompanied worksheets introduce students to combined activities using the parallel words of reality and models, which we assume will help them to gain better understanding of Optics.

We believe that this separated approach to optical phenomena will help students distinguish what is real and what is not, also using models is a choice which is widely used to explain phenomena. For example, the existence of the light ray in the Model world and its absence in the Cosmos world, may help students overcome one of the most common relative misconception.

The up to now pilot use of the software by students and science teachers, especially during open investigation and what-if activities, have shown great acceptance and interest.

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