AN OPEN LEARNING ENVIRONMENT FOR THERMAL PHENOMENA

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ABSTRACT

In this work we present an open learning environment, suitable for teaching Heat and Thermodynamics. The software consists of two independent visual laboratories (one for Heat and the other for Thermodynamics) and a series of relevant multimedia themes on technology and everyday life. The package has an open and dynamic structure, that allows the teacher to compose virtual experiments and re-organise the available multimedia themes, according to the needs of his class. And a pilot evaluation based on the attitudes of experiences physics teachers is also presented.

INTRODUCTION

Teaching and learning in Sciences is not limited in accumulation of knowledge on concepts, laws or phenomena, but, on developing of specific skills as well, that are related to the application of knowledge, development of scientific thinking and skills on problem solving (Woolnough-1989). Much of the current curricular reform effort in physics is based on the idea of interactive engagement of students and active learning. (Hake-1998). Interactive engagement teaching methods take different forms, starting from the use of technology in order to give a more two-way conversation to a traditional lectures (Novak-1999), while other efforts use recitation sessions as important supplements to instruction (Heller-1992, McDermond-1998). In some curricula focus is drown on discovery learning in the laboratory, either as a part of a larger course (Sokoloff-1995) or as the main component of course itself (Laws-1997). All recent curricula however force the student to play a more active role in the learning process, increase the amount of interaction with his peers and instructors, and emphasise both in conceptual understanding and quantitative problem solving as well. Recent research has shown, a significant improvement of students' conceptual understanding in classes where interactive engagement was adopted (Hake-1998).

Curriculum material and educational software in particular, has followed these efforts for interactive engagement. In close reference with learning theories, the educational software follows an evolution of three generations (Winn-1993), from behaviourism to constructivism. In earlier generations, software mainly focuses in context. Following the advances in information technology, availability of systems and tools and increase of computing power, focus is gradually shifted into ways of visualisation of context, to user interactivity. Recent trends are open learning environments, that are based on but also extend theory of Papert (Papert-1991), where knowledge is gained through interactions, not only with objects of the

real world, but with virtual objects as well, that could closely resemble in properties the real ones. Microworlds and open-ended visual laboratories are typical examples of open learning environments. In an open-ended visual laboratory, the user (student) can construct on his computer screen a virtual experimental set-up, conduct the experiment, take measurements, observe and compare graphs, etc. Linked multiple representations, and the convenience of direct and easy application of various experimental configurations makes the visual laboratory an attractive and valuable tool for parametrizing and investigating physical systems, that enhances the ability of experimenting and engages new styles of learning (Lajoie-1993).

In this work, we present the design and the implementation of an open learning environment suitable for studying thermal phenomena. The open learning environment consists of two visual laboratories, one for experiments on heat-temperature and the other on thermodynamics. The open learning environment is accompanied with a series of worksheets, based on the actual curriculum in Greek secondary education. And a pilot evaluation based on the attitudes of experiences physics teachers is also presented.


DESIGN PRINCIPLES

Thermal phenomena are in many curricula the introductory course to physics in secondary education. It is usually treated both experimentally, in a real laboratory, and with traditional teaching methods. Though simple experiments on thermal phenomena are considered as easy hands-on experiments, and qualitative interpretation is straightforward in most of the cases (Linn-1991), a quantitative interpretation is difficult due to the complex nature of thermal interactions (Kesidou-1995). The limitations of the real laboratory, namely:

- the slow rate of thermal phenomena
- the difficulty of parameterisation in real world,
- the deviation between the simplistic (introductory) theory and complex experimental results,
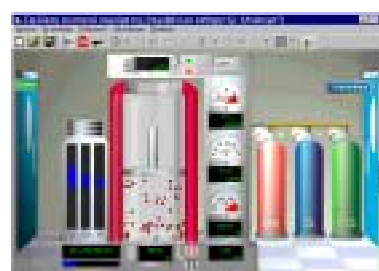- and the absence of multiple representations in real world

were the guidelines for the design of an open learning environment, aiming in the experimental approach in teaching thermal phenomena, both as introductory and as advanced course in secondary education.
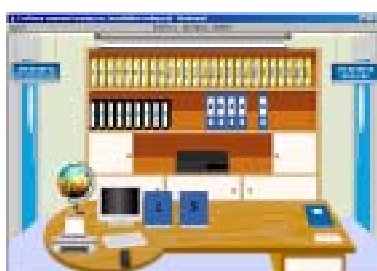
The visual "Heat-Lab"   The visual "study room"   The visual "Thermodynamics-Lab"
Figure 1: The Open Learning Environment for Thermal Phenomena

The open learning environment (fig.1) consists of two visual laboratories, one for experiments on heat-temperature and the other on thermodynamics. The two laboratories are linked through a visual study-room, a library where student can find resources relevant to his study (Psillos-2000). Laboratories and library are designed as three independent rooms: The user (student) first enters in the study room and then he can go to either of the laboratories. Each of the rooms has the visual appearance of either a laboratory or a study room. Visual realism is used for motivational purposes, appealing to user's positive attitude. A pseudo-3D representation has been adopted, that signals to the user's attention, allows direct recognition,

but also keeps visual complexity to a minimum, so that it does not over saturates the users, nor it distracts attention (Rieber-1994). Realism is also extended to commonly used practices, for example, the user can take a book from the shelf and open it on the study table, or put the beaker on the working bench in the laboratory. Manipulation of objects is simple and direct, following the usual windows metaphors (click for select, drag and right-click for properties).

a. The study room

The study room is the logical link between the two laboratories. A typical screenshot is shown in Figure 2. It visually represents a modern study room, with virtual e-books, notepads and multimedia material. The student can use the study room to find material relevant to his subject, make a research on Internet, communicate via email, etc.

The resources that are available in the study room are in modular form conforming for a knowledge base system. Each subject is within a folder and different folders make an e-book. Each folder consists of several interconnected html pages. Thus, e-books can be easily updated or new folders can be added from resources found in the Internet. The teacher can visit the study room, drag books or tapes from the shelves, and leave then on the desk for his students. Programming-wise, this action corresponds to making links available to the students. Links are pointing to directories. Folders in an e-book are subdirectories. The studying desk is the shared directory in the html tree structure. The teacher could also selectively pick some folders from different books and leave them on the desk, create a new e-book with the folders that he had selected. Programming-wise, this action corresponds to a dynamic re-arrangement of the available resources. Additionally, the teacher can modify existing resources, by a simple html editor, or add a new one, as a new directory and subdirectories.

Figure 2: The visual study room

b. The visual laboratories

Each of the two laboratories is a physics microworld based on precise underlying physics, it visually represents a real physics laboratory, and consists of

- Objects (beakers or containers) and materials that can thermally interact exchanging heat
- Virtual instruments (gauges, thermometers, chart recorders, etc) for measuring, monitoring and recording the thermal interactions.

The user, student or teacher, can construct his own virtual experimental set-up by simple and direct manipulation of objects, use the virtual instruments to take measurements, observe and compare graphs, etc. Each of the laboratories operates in two modes: In the "design" mode, the user can set-up and save the experiment having full access to all objects, materials and

virtual interments in the lab. In the "run mode", only those objects that were selected for use in the design mode, are available. By default, the "design mode" is assigned to the teacher, and the "run mode" to the student. Thus, the teacher can fine tune the complexity of the experimental set-up and the experimental conditions for his student.

The key characteristic of the laboratories, is the multiple representations that consists in real time animation. Physical quantities can be measured and represented as graphs of the recorded measurements. Both data measurements and current state of the experiment can be saved and retrieved for further work and comparison.

The importance of date graphs, as an alternative symbolic representation in physical phenomena, and the conceptual difficulties that students have in assigning physical to data graphs, has been stressed by many researchers (Swatton-1995, Leinhardt-1990). In our approach, measured physical quantities are "animated" as graphs in real time. Though the term "animation" is arguable for data in graph, the important feature here is that data in the graph are observed to change along with the animated experiment. Therefore, the learner can make a connection between the "state" of the data in the graph, and the "state" of the experiment running in the animation. Graphs appear as popup windows, so that data animation can be incorporated only when its attributes are congruent to the learning tasks set by the teacher. Thus, different tasks can be achieved, from qualitative observation to intensive data manipulation.

c. The Heat laboratory

A typical screenshot for the "Heat" laboratory is presented in figure 3. The laboratory visually resembles a real-world laboratory suitable for experiments on thermal phenomena (Lefkos-2000). It consists of a *working bench* on which experiments can be performed *objects* (beakers and heaters) to compose the experimental set-up, *materials* (solids or liquids) who's thermal properties are to investigate, and *virtual instruments* (thermometer, chronometer, heat-flow sensor) or *displays* (data charts, blackboard).

Figure 3: The Heat laboratory

As thermal phenomena are the introductory course to physics in Greek high school, the main design approach for the environment is to help the student familiarise with experimental techniques. The student can use the environment with simple and direct manipulation: He can move the beakers, fill them with liquids, add solids or solvents, put one beaker into another, etc. The mouse pointer changes form according to the desired action, from a "hand" to indicate select and drag, to a bottle to indicate "filling". The student can investigate simple of complex

thermal interactions and perform experiments on heat and temperature, phase transitions and thermal equilibrium.

In design mode, the teacher can select the beakers and the materials for his students, by dragging them on the working bench, and save the experimental set up. He can also pre-set the properties, for example, if the beaker is thermally isolated or it can interact, what material the beaker is made of, and thus specifying the thermal conductivity of the beaker, what size the beaker may have, etc. The teacher can also define, whether the student may have access in changing the parameters and which of them, and thus fine-tune the complexity of the phenomena and the degrees of freedom in parametrizing his student will have.

d. The Thermodynamics laboratory

A typical screenshot for the "Thermodynamics" laboratory is presented in figure 4. The laboratory visually resembles a possible real-world laboratory suitable for experiments on Gas Laws and processes (Refanidis-2000). The main component of the laboratory is the *gas chamber*. The experimental set-up is pre-set, with build-in gauges to measure macroscopic (P, V, T) or thermodynamic (mean kinetic energy, ΔU, Q, W) variables. The gas chamber can be heated or cooled at desirable rate, change volume, with thermal or adiabatic shielding.

Figure 4: The Thermodynamics laboratory

The student can perform simple laws or complex experiments (thermal cycles) with different gasses, calculate efficiencies, check temperature limits and select thermal processes for optimum operation, etc. Gasses (He, O_2, CO_2) are treated as real ones in the van der Waals equation. As the laboratory is designed for an advanced level course, the main design approach for the environment is to help the student familiarise with different graph representations of the state variables. Thus, can use the graphs either in on line animation, or can change variables in the axes after data have been collected.

ALGORITHMIC APPROACH

The open learning environment was designed and programmed using Microsoft Visual Basic 6, as a choice for the time-effectiveness of a prototype and structured object oriented programming. All element in either of the laboratories is an *object* in o-o-p that conform to two basic methods: "evolution", which calculates the new state for each object based on the current state and thermal interactions and "update", which undertakes the visual displaying of the object, based on it's current state.

a. The Heat laboratory

In the Heat laboratory, there are two main type of thermally interacting objects, materials (ex. water) and containers (ex. beaker) that contain materials. Both types of objects have physical properties (mass, density, temperature, specific heat, etc), and values that correspond to real material. The thermal interactions are calculated by solving numerically the heat transfer equation. The Physics problem is formulated with two simple principles (Hatzikraniotis-1999):

1. Heat is transferred through the container from one material to another. The rate of heat transfer is determined by the temperature gradient and the thermal conductivity of the container
2. Heat flow can cause
    a. change in temperature to:
        *   the material inside the container, depending on specific heat of material
        *   the container itself, depending on specific heat of the container
        *   the material outside the container (if one container is within another), or to the environment (if container is the outmost)
    b. a phase transition to:
        *   the material inside the container, depending on latent heat
        *   the material outside the container, depending on latent heat

Having formulated the problem, heat flow is solved as an iterative process for all containers and materials, at subsequent time steps. The advantages of this formulation are:

1. containers are fully parameterised, thus, a variety of different problems may be set with variable complexity, i.e.
    a. If thermal conductivity is zero, then container is thermally isolated.
    b. If specific heat is zero, then container is thermally inactive in the heat exchange.
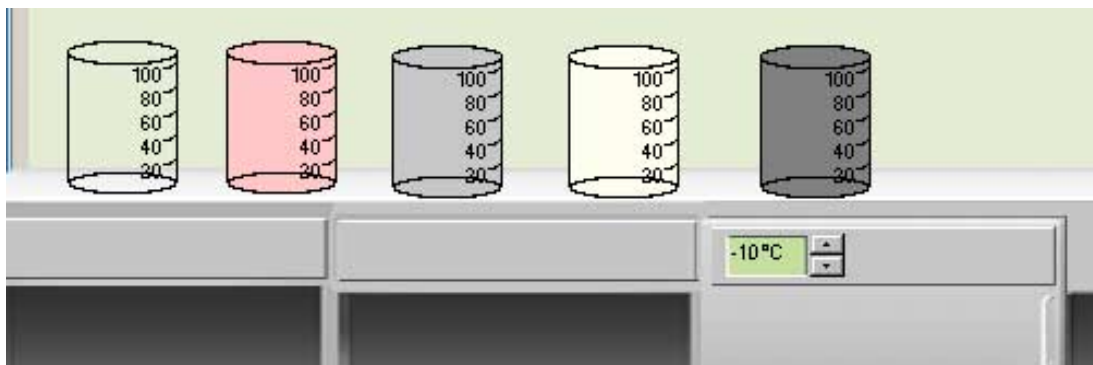   c. If emissivity is zero, then container does not radiate heat to the environment

Figure 5: glass, ceramic, metal beakers of the same size. The last two beakers have different emissivity

    d. If thermal conductivity is not zero, then the rate of heat exchange depends on the material the container is made of (metal, glass, ceramic, in fig.5)
    e. If specific heat is not zero, part of the heat exchange is absorbed (or released) by the container itself, and this depends on the material (specific heat) and the size of the container (fig. 6)
    f. If emissivity is not zero, then radiated (or absorbed) heat depends on the outer surface, i.e. on the size of the container and the emissivity (black and white beakers in fig. 5)
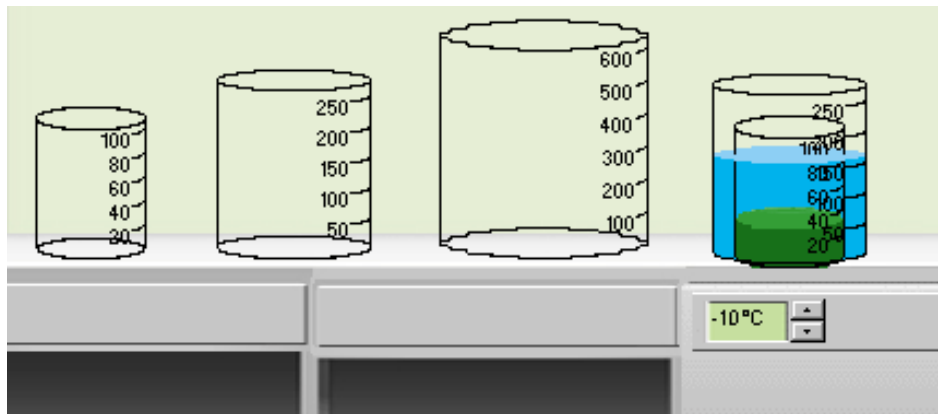
Figure 6: glass beakers of the deferent size. Beakers can be placed one inside the other.

2. Containers can thermally interact with each other, and with the environment. Laboratory environment is considered as having infinite heat capacity, thus temperature does not change, however, it can be set to any desired value from -10 to +110°C. Thus, a number of experiments can be set, asking students to face "unusual" situations, and examine their deeper understanding in thermal interactions. In Figure 7, we examine thermal equilibrium in a fictional environment of 100°C.
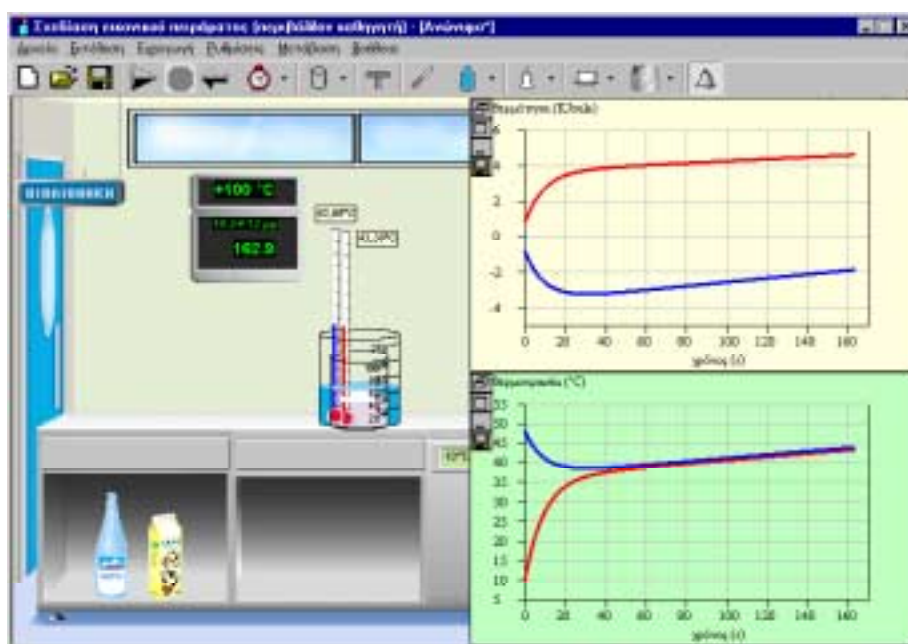

Figure 7: Thermal equilibrium in a fictional environment of 100°C

b. The Thermodynamics laboratory

In the Thermodynamics laboratory, the main algorithm is adopted on the kinetic theory of gasses in a closed vessel. The generalised van der Waals equation $(P+\alpha/V^2)\cdot(V-\beta)=nRT$, permits the parameterisation for different gasses ($\alpha=0$, $\beta=0$) for ideal gas, (He) or ($\alpha\neq0$, $\beta\neq0$) for real gas (O_2 or CO_2).
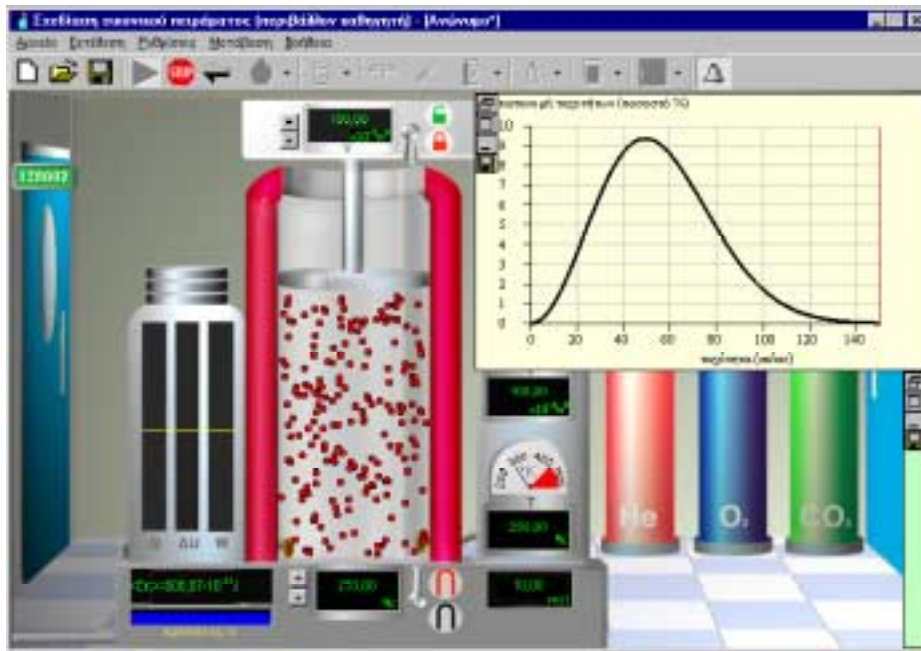
Figure 8: Microscopic modelling of gas molecules and distribution of speeds

For the microscopic modelling, we consider gas molecules as hard spheres, elastically colliding with each other. Molecules interact with the walls and follow a Maxwell-Boltzman distribution of speed. In figure 8, the student can change the temperature of the temperature f the gas chamber, observe the change of both the motion of the there molecules inside the chamber and the dynamic evolution of the M-B distribution. He may also change gas and he will observe, for the same temperature, both qualitative and quantitative changes in the graph that are due to the difference in mole mass. The emphasis in "working with graphs" is also evident in figure 9, where, the student is asked to observe the usual Carnot-cycle graph in a typical, and in an alternative representation.
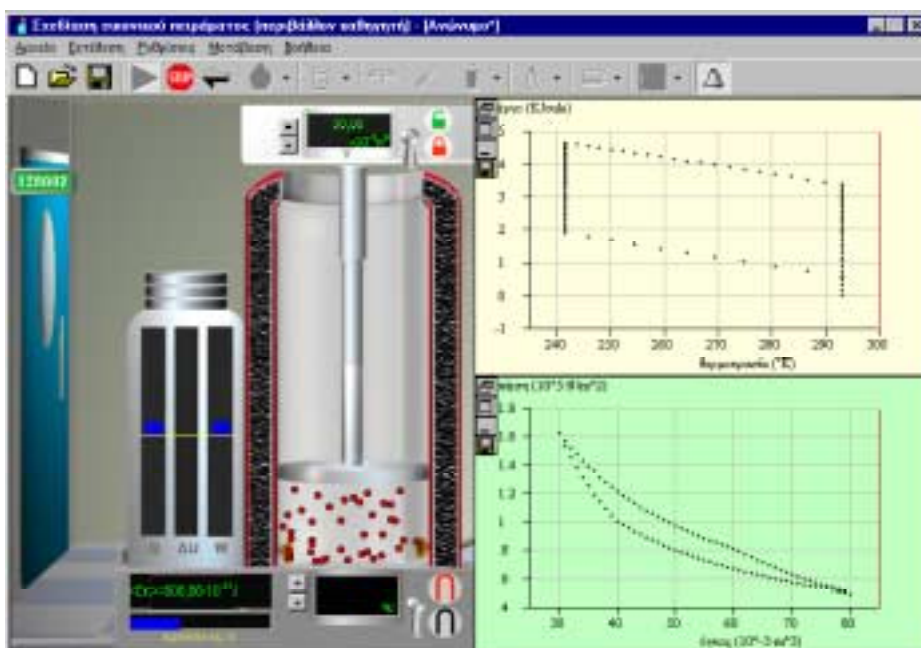

Figure 9: Carnot cycle in a typical (lower graph) and alternative representation (upper graph).

IMPLEMENTATION - EVALUATION

A series of in class activities were designed for use with the open-learning environment, in teaching of thermal phenomena. Activities were designed in close compatibility with the Greek curriculum. A pilot evaluation was carried out on a group of 40 high school teachers, all of them heaving vast, more that 15 years, of experience in teaching physics. Teachers were selected so that teachers in the group were having a different background and experience in using a computer, either as an ordinary user, or with in-class activities. Teachers were asked to examine and go through the activities, as a student may have done. The key question was to investigate "How teachers' evaluation of the open learning environment is affected by their experience in using the computer. The main findings of this pilot study were (Lefkos-2001):

a. Teachers could easily follow up easily the planned activities, despite their experience in using the a computer
b. They found the open learning environment easy to use and user friendly both to them and to their students as well.
c. They estimated that their students could easily follow up the activities in the visual laboratories.
d. Teachers have shown a positive attitude in using the open learning environment, and found that activities are easily adopted and helpful for their teaching.

CONCLUSIONS

In this work we present an open learning environment, suitable for teaching Heat and Thermodynamics. The open learning environment consists of two independent visual laboratories (one for Heat and the other for Thermodynamics) and a study room. Physical phenomena in the two laboratories are represented with a high degree of accuracy in underlying physics. High degree of parameterisation can reveal the complex nature of thermal interactions. Teachers in our pilot study have shown a positive attitude in using the open learning environment, and found the environment easy to use and user friendly, despite their different background and experience in using a computer.

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