A STUDY ON SCIENCE TEACHERS´ USE OF DESIGN FEATURES OF A SIMULATED VISUAL LABORATORY TO DEVELOP ACTIVE INVOLVEMENT OF STUDENTS IN THE TEACHING OF THERMODYNAMICS AT SENIOR HIGH SCHOOL

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ABSTRACT
In this paper we describe a small-scale exploratory study on how in-service science teachers of Greek senior high schools can take advantage of facilities included in a simulated visual Lab to create innovative open activities for teaching Thermodynamics. The visual laboratory used, is part of 'SEP', a micro-world for the teaching of thermal phenomena that is designed as an open environment with a high degree of user interaction and direct manipulation of virtual objects, multiple real time graphs and high consistency with scientific content.
The sample of the study consists of experienced high school teachers. Teachers were asked to propose ways they envision to use the open environment facilities of SEP to improve students' involvement and make up for some difficulties in specific chapters of Thermodynamics. The results show that the teachers managed to compose ways of didactic exploitation in the form of worksheets for their students. They suggested specific well-articulated ways to explore the open nature of the micro-world within its specification, while, at the same time, they revealed a positive disposition concerning its possible use.

KEYWORDS
Educational Software, Simulated Visual Laboratory, Thermodynamics

INTRODUCTION

The use of ICT in a science laboratory has been implemented for some decades in many ways, and its value and merits are well known and documented. In the last few years, several kinds of computer-based laboratories have been proposed, namely, Microcomputer Based Laboratory (*MBL*), Simulation Based Laboratory (*SBL*) and Video Based Laboratory (*VBL*).

A simulated visual laboratory (*SVL*), bridges the gap between MBL and SBL, as it inherits the major characteristics of simulations and holds their strong points, i.e. the capability to change the parameters of an experiment, generating each time different responses. The computer user interface is realized by direct manipulation of virtual objects that could closely resemble in properties and appearance the real ones. In an open-ended visual laboratory, the user (student) can construct on his/her 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 make 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, S. et al. 1993).

Although several successful applications of ICT in Physics Education have been identified, from computer based experiments and processing to simulations and modelling, and even though educational research has demonstrated its effectiveness, still, the level of integration in the everyday school practice in many countries is not high. Recent projects have focused on the nature of difficulties arising when teachers are asked to adopt an innovative ICT intensive teaching sequence (2), or are asked to investigate new ways of "good practice" (3). In order that ICT-intensive teaching innovation be effective and receive widespread use, three conditions have to be met, namely, it has to be *authentic*-that is, it must address real educational issues, it has to be *adoptable*-it must be easy for the instructor to integrate into his/her class and for the students to learn to use, and it has to be *adaptable*-that is it must be easy to modify so as to fit into the particular instructional setting.

The objective of this paper is to explore how in service science teachers of Greek senior high schools can take advantage of facilities included in a simulated visual Lab to create innovative open activities for teaching Thermodynamics at senior high school. The context chosen for the present study is from the field of Thermodynamics, for its known difficulties as multi-parametric phenomena, where research has shown that students find it difficult to correlate macroscopic variables to microscopic (Rozier, S. et al.. 1990), to assign pressure to its microscopic origin (de Berg, K. C., 1992), to express the macroscopic changes in gas-laws with microscopic reasoning of the kinetic model (Viennot, L. et al. 1994), and understand the sense of translation among various graphical representations often used in Thermodynamics text books with the underlying physical quantities (Leinhardt, G. et al. 1990).

THE VISUAL LABORATORY

The visual laboratory used in the present study, is part of 'SEP', a micro-world for the teaching of thermal phenomena that is designed as an open environment with a high degree of user interaction and direct manipulation of virtual objects, multiple real time graphs and high consistency with scientific content (Psillos, D. et al. 2000).

The features of SEP have been presented in other studies (Psillos, D. et al, 2000) and will be briefly outlined in the paper for the sake of coherence. The open learning environment consists of two visual laboratories, one for experiments on heat-temperature and the other on thermodynamics (fig.1). The two laboratories are linked through a visual study-room, a library where students can find resources relevant to their study. Each of the two laboratories is a microworld based on precise underlying physics; it visually represents a real physics laboratory consisting of *"objects"* and *"materials"* that can thermally interact exchanging heat and *"Virtual instruments"* (gauges, thermometers, chart recorders, etc) for measuring, monitoring and recording the thermal interactions.

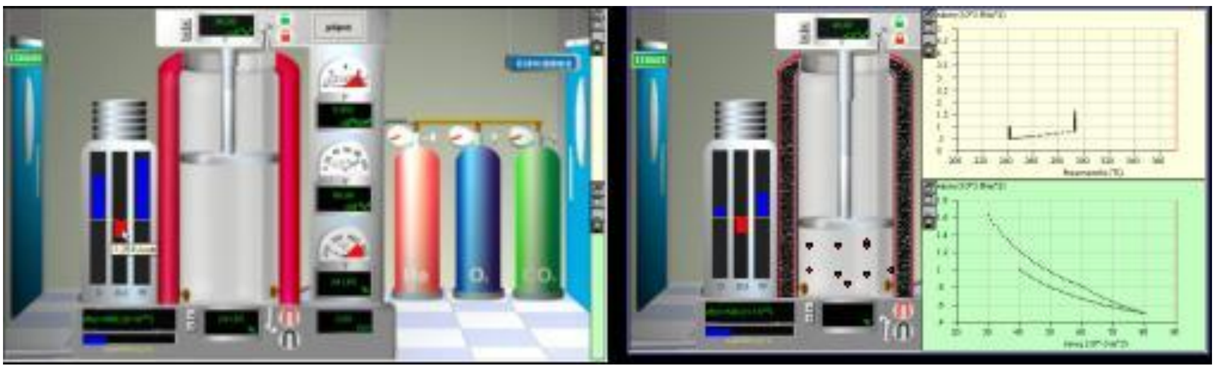

Figure 1. Typical screenshots of the visual lab on Thermodynamics

Typical screenshots of the "Thermodynamics" laboratory are presented in figure 1. The laboratory visually resembles a possible real-world laboratory suitable for experiments on Gas Laws and related processes. 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. 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. Gases (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 gain familiarity with different graph representations of the state variables.

There are two kinds of similar software implementations in the area of Thermodynamics: a) Numerous focused environments, designed for the specific study of particular phenomena, such as gas laws, the Carnot cycle, molecular speed distribution etc (see Internet link in References). These are mostly Java applets that can be found easily in the Internet, more or less visual labs with a limited degree of user interaction, but mainly different from an integrated single tool for a comprehensive study of the topic. b) A few tools that can be categorized as integrated environments for the above study. For example "Corel ChemLab", a visual lab for teaching (mainly) chemistry and gas laws. We believe that its lack of graphic representations leads the user to perform measurements and construct their own graph afterwards, which resembles the constraints of a real lab. Another example, "CPU Simulators- Ideal gas simulator" (The CPU project), offers multiple representations as well as synchronous graphs and a higher degree of parameter control. Its design tendency to emphasize and develop skills of constructing the (visual) experimental set could disorientate high school students of thermodynamics, while it could be very beneficial in other areas, such as electricity.
In this context, the key questions to explore in our investigation are:

- How easy would it be for an experienced Physics teacher to adopt the visual laboratory?
- How easy would it be for a teacher to compose ways of didactic exploitation of the simulated visual Lab in the form of worksheets for their students?
- How easy would it be to adapt the open-character of the laboratory so as to enhance his/her students' active involvement and make up for known difficulties in the teaching of Thermodynamics?

DESIGN OF THE STUDY

i)Methods

This is a small scale exploratory study following a qualitative methodology. SEP was presented, discussed and handed out to teachers so that they familiarize with it for as long as they would think appropriate. The teachers were asked to propose ways they envision to use the open environment facilities of SEP to improve students' involvement and make up for some difficulties in specific chapters of Thermodynamics such as the known complexity of P-V-T laws and the students' difficulties to describe the macroscopic changes with microscopic reasoning. The study was structured in two phases, namely planning of worksheets by teachers and subsequently in depth interviews. Data were taken in two parts: (a) Analysis of the worksheets composed by the teachers, and (b) Semi-structured interviews.

ii) Sample.

There were 6 experienced in-service teachers who participated in this exploratory study. The teachers were selected by their willingness to participate and their attempt to compose ways of didactic exploitation of the simulated visual Lab in the form of worksheets for their students. Three of the participating teachers had an average experience in using a computer and limited, if any, experience in educational software. For the purpose of our study, we considered them as *"content experts*". Their in-class lab-work practice varied from minimal to adequate. The other three teachers, have been selected amongst those who had attended an one-year training course on ICT-based teaching in Science. In addition to content, these teachers were considered as *"computer experts"*.

iii)Instruments

a. Planning worksheets.
In the first phase of the research the teachers were given a list of topics or problems quoted in the school textbook, and hints for instructive approaches, that are typical in lab-work. The list consistent of 12 topics, all based on the current text-book, six of them from the book-session of "theory" and six from the session of "exercises", "numerical problems" or "applications". Examples of theory- based topics are: "Work in gas detonation", "1st Law of Thermodynamics", "Molecular speed distribution", "Gas transformations", etc. Examples of exercises or problems are: "What is the meaning of the "higher" position of one isotherm curve, as regards to another, in the same P-V graph", "When is a gas transformation reversible? ", "How does the pressure in a car-tire changes if the tire warms at constant volume? ", etc. Teachers were asked to compose lab activities in the simulated lab, declare the aims and objectives, and set up a worksheet for their students. Each teacher had to work independently of the others, without any guidance or assistance from the research team. Hints for the instructive approach were given only as a potential list to select from:

- Compose an interactive simulation to be used by the teacher as a visual aid for instruction.
- Set up a qualitative laboratory exercise for students.
- Set up a quantitative laboratory exercise for students.
- Outline a training demonstration to a fellow teacher

b) The semi-structured interview
The teachers participated in personal interviews of 45 minutes approximately, after they had finished dealing with SEP and implemented the required worksheets. The interview was organized in four parts:
1. Questions on their background, teaching experience, lab work experience, computer knowledge, educational software.
2. Questions on their perceived usability of the environment, where crucial parameters for us was their time spent to familiarize and their time spent to compose their worksheet.
3. Discussion and justification of their specific teaching approach (their worksheet), concerning the chosen topic, aims, student activities, etc.
4. An overall evaluation of the environment, its major benefits and disadvantages, its compatibility with curriculum and school textbook, etc.

RESULTS

i) Data form the worksheets.
The six participating teachers came up with 15 worksheets in total, contributing 1 to 7 each. To our surprise, *'content experts'* outnumbered by 12 to 3 the contribution of *'computer experts'*. Our list of 12 proposed topics was widely covered; 5 topics were selected once and 4 twice. Three topics were not selected at all, while teachers themselves added 2 more another to the original list. Non-selected topics, though included in the textbook, were not taught during the school year. Topics that were *"theory"*-based to *"exercise"*-oriented were equally selected (7 to 8). A rather high tendency has been observed for topics that offer an intensive use of graphic representations.

The objectives as quoted in the worksheets belong to two categories: the first and most frequent category concerns cognitive objectives, as *"to comprehend the significance of elementary change"*, *"... proof of Boyle's law"*, etc. The second category includes objectives on skills, as: *"to observe the change of slope of an isotherm to adiabatic curve in a P-V graph"*, or *"…how to make a graph"*.

Concerning the adopted instructional approach, there is a clear preference to active student engagement in experimental work in 11/15 worksheets rather than a demonstration performed by the teacher himself as a visual aid to the class, which was included only in 2/15 worksheets. The more frequent choice in 8/15 worksheets is the qualitative experiment as compared to only 3/15 suggestions involving quantitative experiments. Such a choice would potentially offer additional approaches alternative to pure mathematical tools, a lack of approaches that teachers seem to experience in their everyday practice.

The educational added value of the teaching scenarios that teachers developed reflects their experience in actual lab-work. In most of the cases, the designed activities follow the typical structure of a worksheet for a real lab; initial conditions are well specified, students are asked to run the experiment and study the graphical representation. Sometimes, the steps to execute are expressed in a severe and frugal way; at other times, objectives are mal-expressed and reduced to execution steps. The structure of the worksheets clearly reflects each teacher's limited experience in actual lab-work as well as their usual teaching practice, as verified in the interviews, rather than their limited familiarization with ICT.

ii)Data from the interviews
Based on interview data, we estimate that teachers spent rather limited time dealing with SEP: from 0,5 to roughly 5 hours for their familiarization with the visual lab. The time required for their contributed activities also varies from 0,5 to 3-4 hours, with a more frequent value of roughly 2 hours.

In reference to the topics they selected from the 12-topics list, teachers tend to justify their choice, according to their practical experience, either referring to difficulties that their students face or, also the possibilities for experimentation for their students, in correlation with the use of graphic representations:

D. Mas. (computer expert), for the topic "Distribution of speeds in gases":*"for the students to understand why should we select to make the distribution with specified axes… what is the meaning of distribution… I find it as a major difficulty for students to understand. Generally, the statistical treatment requires more time, and it is real time-consuming to try to pass the real meaning of statistics in this case…. Using the visual lab I can easily show …this is the basic distribution of speeds, this is the mean, the median, the RMS value, and look how do they change if we change the temperature of the type of gas".*

Sometimes the choice of topic is strongly influenced by existing infrastructure in a typical classroom where Physics is taught, which mostly looks more like a lecture hall than a lab.
D.M (content expert) *"... I do not think I can bring more than one PC in my lecture hall, and on this basis, what mostly interests me, is a pictorial, a visual representation in my teaching…"*.

When infrastructure is there, and physics class takes place in the computer-lab of the school, the majority of teachers are in favour of the active student engagement on qualitative experiments. The arguments extended from the requirements of particular topic to teach, to the personal (mostly unjustified) preference of the teacher to this type of work. They argue on the significance of the qualitative approach, which they claim that according to their experience will help the quantitative study in a later stage. They seem to find the visual lab as a valuable means that fulfils their need:
D. Mas.(computer expert):*"... and moreover because with the qualitative study I reach my objectives of instruction, that is to say I show the dependence of speed from the temperature."*
K. A.(content expert): *"...through such process a better assimilation of concepts is achieved… student himself is involved in the process, see certain things for himself and can clarify certain significances."*
Th. K.(computer expert):*"...I do have a personal preference in qualitative approach. Perhaps the spirit of the current curriculum reform is to go in qualitative, let students not to memorize bits and pieces… it unblocks their brain… and they can more easily come to resolve exercises also."*

In their majority, teachers agree that the major tool of the virtual lab is the synchronous multiple graphic representations in combination with the possibilities of experimentation:
M. K.(content expert):*"...graphic representations. It is important, not only to observe the experiment, but the evolution of graphs as well".*
A. A.(computer expert)*: "First of all, it is not possible (at least for my case) to conduct the law of Boyle-Mariotte in a typical class, then, there is a series of other experiments which seem possible to be performed. I cannot do them in any real lab. I believe, visual lab, covers the lack of a laboratory for thermodynamics. Secondly, some experiments can be performed in a real lab as well, but they do require so much time, while here the time is minimum.".*

In reference to the compatibility with the school textbook teachers argued that the visual lab enhances problem solving and performance on multiple choice exams. Taking into account the particular conditions of pressure of time that prevail at senior high-school in Greece, as students are to be prepared for the University exams, teachers stressed that using the visual lab, is not a waste of valuable preparation time, but on the contrary, time is gained, due to the possibilities of conceptual comprehension that active student engagement offers:

D. M.(content expert):*"reformed curriculum has a new spirit with the questions of multiple choice… most of the questions require critical thinking and qualitative approach…in thermodynamics, it is essential for the student to know the theory, to distinguish one type of transformation from another…"*

Th. K.(computer expert):*"First of all visual lab saves a lot of time for the teacher, time for lecture… teacher can easily pass from all states in a P-V-T change… student can see them…make any graphic representations he wishes in order to show cycles etc, and he verifies each time the law with the available data."*

DISCUSSION

It seems that the key point for a successful and effective use of an ICT innovation, like a visual lab, is to identify what do teachers consider as *authentic*, and to what extent do they consider it addresses their educational needs. Although not using the terminology of educational research, teachers identified the crucial points of simulations, namely, they think that simulations can help their students:

- *To make sense of translation among different representations*. As scientists, they do know that in physics, information about a physical system is represented in many different ways, using words, equations, graphs, diagrams, tables of numbers, etc. They do realize, rather through intuition than by knowledge or experience, that showing animations of a dynamical system and tying it to a coordinated graph, diagram or plot, when used in an appropriate lesson, may significantly help students to develop skill in using different representations to help them make sense of physics.
- *To build mental models of physics systems*. Teachers know, mainly from their own teaching experience, that students do not necessarily have the ability, the experience or the imagination to put together what they are reading in text, or hear in a lecture, with what they see on a plot, into a coherent and sensible picture. As scientists themselves, teachers do have the feeling that many of our "coherent pictures" in physics are mental models of interactive objects having quantities and measurable properties. Teachers, though not explicitly stated, seem to follow the approach that visualizations may help students in building mental models.

Although these two points are crucial to simulations, other points of equal value and unique in a simulated visual laboratory seem not to be recognized. In most cases, the simulated laboratory has been considered as an extension or substitution of a possible real one, which in the case of thermodynamics is not available. Biased by their need for a laboratory to cover thermodynamics, they have tried to reproduce lab-activities that would be typical in a real laboratory. The *authentic* need is for a real lab, or a substitution for a real lab. Consequently, even though teachers had themselves explored (and appreciated) the open-character of the simulated lab, and the need of student involvement was recognized, students' active engagement was limited up to the scheme "perform a pre-scheduled experiment" and "work with a graph". The unique possibilities offered by a simulated laboratory, i.e. *let the student explore the phenomena on their own,* and thus let the laboratory *serve as a sketchpad* on which students can display and describe their understanding of physical phenomena, were not examined. On the other hand, it must be recognised that the Greek Physics curriculum does not practically encourage open activities, but mostly promotes the support of unquestionable scientific knowledge. It is not so strange then that teachers consider any type of lab (real or virtual) as an aid towards that purpose since this is part of the dominant educational culture:

K. A. (content expert): *"Perhaps the software is more helpful (than a real lab). This happens because all the parameters that can make experimental results to deviate from the perfect law, are not there. So the software may be more persuasive for the student. Many times we have come to the point where we have performed lab activities in real conditions and manage to defeat the (Physics) law…".*

CONCLUDING REMARKS

In reference to the key questions of this study, it is clear that it was easy for teachers to adopt the visual laboratory; its learning curve is smooth and fast and teachers developed a positive attitude to the simulated lab. Spending a rather limited time, they came up with a number of contributions that cover practically the majority of topics in thermodynamics. They have examined several ways of didactic exploitation for the simulated visual Lab. Based mainly on their experience, they tried to enhance their students' involvement, adopting laboratory exercises rather that demonstrations. They believe that active engagement will help students to overcome the difficulties in the teaching of Thermodynamics, which they know by experience. However, certain unique facilities of the simulated laboratory were not sufficiently explored, probably due to the lack of extensive experience and skill in using open simulated laboratories in actual teaching.

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