

INTEGRATING ICT TOOLS IN A LABORATORY TEACHING SEQUENCE OF THERMAL PHENOMENA

Lefkos Ioannis, Psillos Dimitrios, Hatzikraniotis Euripides

ABSTRACT

This work refers to aspects of the development and implementation of a sequence of ICT based laboratories and their integration in high school physics in the area of heat. The objective of extensive use of ICT based tools in the labs was to facilitate the enhancement of students' understanding of the main concepts of heat as well as the development of their graphing and experimental skills. The ICT tools used in this sequence are the "Coach II" - MBL platform and the visual laboratory "Thermolab". MBL provides a strong link between real-life phenomena and their graphic representation while "Thermolab" provides an open environment in which students can quickly and easily change or structure experimental set ups to conduct parametric investigations of the phenomena. The main lab sequence consists of 4 modules: thermal equilibrium, calorimetry, phase transitions and heat radiation. Emphasis was put on enhancing students understanding of temperature equilibrium following research on students' conceptions. The implementation of the sequence took place in a class of lower high school (age 13-14 yrs.). Preliminary analysis of results suggest an understanding of several aspects of thermal equilibrium and use of the "caloric" model by the students, and the development of their graphing skills.

KEYWORDS

Simulated Visual Laboratory, ICT-based Teaching, Thermal Phenomena.

INTRODUCTION

Much attention is given today in modern curricula to the active role of student in the learning process. Much of the current curricular reform effort in physics is based on the idea of interactive engagement of students and active learning. Curricula focus on the increase of student's interaction with his peers and instructors, and emphasise both on conceptual understanding and quantitative problem solving. 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. New technologies by now have reached a certain point of maturity, not only from the point of view of the widely spread applications in a variety of aspects of everyday life, but also from the view of the exploration of their usability in the educational process. In close reference with learning theories (Winn, 1993), from behaviourism to constructivism, focus is gradually shifted from forms of visualisation of context onto user interactivity. Current trends align towards open learning environments, 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 (simulated) laboratory, the user can construct a virtual experimental set-up, conduct the experiment, take measurements, observe and compare graphs, etc. Linked multiple representations (Leinhardt, 1990; Windschitl, 1998) and the convenience of direct and easy application of various experimental configurations makes the visual laboratory an attractive and valuable tool for parametric

investigations in physical systems, that enhances the ability of experimenting and engages new styles of learning (Lajoie, 1993).

Teaching of Thermal phenomena appears in most (if not in all) curricula worldwide. In some cases, as in Greek high school, it is the introductory topic in Physics. This is why the topic of thermal phenomena is considered as a very critical subject for the school physics learning in general. Students are not only supposed to be learning physics concepts but also to be introduced to scientific thinking and to experimental processes. Within this context, teachers are asked to get over with a multiple challenge: Overcome the common learning difficulties of thermal phenomena, develop the experimental skills of their students at the same time, as for all science topics and, in addition, to introduce students to the scientific way of thinking and exploring natural phenomena.

Despite the fact that Thermal phenomena are one of the typical high school science topics, research has proven (Driver et al., 1985; Kesidou et al., 1995; Taber K. S., 2000) the difficulties in teaching and learning and a great deal of students misconceptions. One of the main reasons for this fact is considered to be the everyday interaction of the students with the concepts and the phenomena, where their senses and common language descriptions are not always in line with the scientific view. We all say “close the door, because cold is coming in” and we all feel cold when walking barefoot on a marble floor and worm walking on a wooden floor of the same house. Additionally, the learning difficulties reported on this topic, derive from the nature of the topic itself. Explanations of thermal phenomena demand the integration of the partial concepts employed, into a meaningful model. That is to combine heat and temperature, because neither one of them can be explained without the use of the other (Arnold, 1996). But on the other hand, the difficulty in distinction between these central concepts of heat and temperature is one of the most “popular” among the recorded misconceptions in physics. Research has proven the persistence of it, even after teaching (Driver, 1994).

Research over the years has concluded on students’ primitive ideas, and much attention has been given to lab-work in the topic to overcome learning difficulties. Experiments on thermal phenomena are usually easily conducted in a classroom without problems. But the really complex nature of thermal interactions results to difficulties in following sometimes a qualitative or a quantitative approach (Linn, 1991; Kesidou, 1995), for the interpretation of the phenomena. Moreover, in a school laboratory set-up, students usually end up filling up the worksheets mechanically without really giving a meaning to the process or to the results. Such an attitude is far away from developing scientific thinking or problem-solving skills (Woolnough, 1989), as demanded by the physics curricula. The essence of Lab-work on the other hand, is for students to get involved in the world of ideas, representing the world of things and to get engaged in a purposeful observation of/and investigation into the world by using especially developed or commonly available objects and apparatus (Psillos & Niedderer, 2002).

In the present paper we describe the design of a teaching sequence about thermal phenomena, with a strong laboratory character and extensive use of ICT tools. The aim was not only to enhance the understanding of the main concepts of the topic, but also the development of experimental skills and graphing abilities of the students.

A MULTILEVEL INTEGRATIVE APPROACH: ICT-BASED LABORATORY TEACHING OF THERMAL PHENOMENA

Following the findings in Hake’s work, interactive engagement teaching methods have taken different forms, starting from the use of technology in order to give a more interactive, two-way conversation form to traditional lectures (Novak, 1999), while other efforts use recitation sessions as important supplements to instruction (Heller, 1992; McDermott, 1998). In some curricula focus is drawn on inquiry learning in the laboratory, either as a part of a larger course (Sokoloff, 1997) or as the main component of course itself (Laws, 1997). Recently, Psillos & Méheut (2001) introduced the term Teaching-Learning Sequence (TLS) in order to identify the close linking between the proposed teaching and expected student development as a distinguishing feature of research-based sequences of medium

level focusing on a specific topic. Designing a laboratory based teaching sequence (Lab-TLS) for thermal phenomena, as suggested in this work, means taking decisions in several levels: The modeling of concepts, the tools used for the implementation and research on students' conceptions and conceptual evolution.

In our work, we adopt an integrative approach for the concepts, and we propose the use of thermal equilibrium as the key concept to build explanatory models for thermal interactions, proposing in this way a holistic view of teaching. Other authors have also pointed out the crucial point of thermal equilibrium, as a key concept (Carlton, 2000). Our suggestion is to build these explanations mainly on the basis of a "heat flow" model. As depicted in figure 1, the "heat flow" model can easily illustrate the thermal interactions either in a two-body case, or in a single body. Research has also shown that "heat flow" model is closer to the views of the students (Linn, 1991; Arnold, 1996; Bisdikian, 2000), and is easier adoptable for the construction of an explanatory model. Thermal equilibrium is a phenomenon that gives ground to this kind of explanatory model that combines the concepts of heat and temperature.

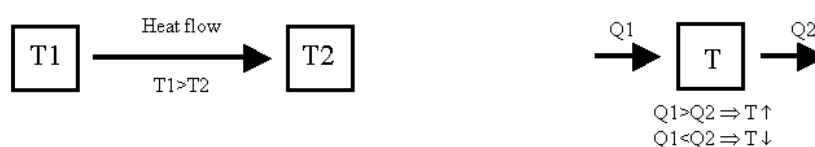


Figure 1. The "heat flow" model (after Arnold et al., 1994)

Several researchers have extensively investigated the learning difficulties in thermal equilibrium (Kessidou, 1993; Arnold, 1994; Thomaz, 1997). Though this topic is still considered to be at the core of the conceptual modeling of heat phenomena, research findings show that it is not easy to overcome students' conceptions. In our work, we find it challenging and appealing to address this problem and exploit the benefits of new technologies in combination with the traditional hands-on experimentation, with a sound pedagogy in mind. We feel that at an introductory level to Science, manipulating objects of the real world relating to the phenomena under study are interesting experiences for the positive engagement of students. Besides that, ICT provides potentially for new ways of viewing, thinking and interpreting phenomena including thermal ones. The issue of integrating traditional and ICT tools deserves further investigation and depends on the goals of each phase of laboratory teaching (McFarlane, 2002; Sassi, 2001).

In this context, we developed an ICT based Teaching Learning Sequence for the study of thermal phenomena secondary students in Greece taking also into account curriculum constraints. In our approach we suggest hands-on experiments for the introductory phase of a phenomenon and simulated experiments for their parametric investigation. Computer based measurements in a typical MBL set up has proved to provide students a strong linking between the real and virtual world of experimentation (Thornton, 1999). So, stepping up from real world to MBL and then to simulated laboratory, we increase the level of abstraction and thus we gradually raise the cognitive load from the object manipulation by hand to concept manipulation by mind.

THE TEACHING LEARNING SEQUENCE ON HEAT

The tools used in the laboratory sections of the sequence, are both conventional and ICT based: Coach (an MBL platform) and Thermolab (a simulated visual laboratory), both sharing and open learning character and the real time connection of the phenomena with their graphic representations, which we consider of crucial importance to our laboratory work.

Coach is a versatile Learning Environment for Science, Mathematics and Technology. Coach integrates all the tools needed for Measurements, Control, Data Video, Modeling, Advanced Data Processing and Data Analysis. Measurement activities enable user to collect data either directly from sensors or from video, control activities use actuators to design automated systems, while modeling activities use and

create dynamical models (Mulder, 2001; Ellermeijer, 1996). Data collected can be further processed with the help of many Advanced Data Processing tools.

ThermoLab is an open learning environment suitable for studying thermal phenomena (Hatzikraniotis, 2001). A typical screenshot for the ThermoLab appears in figure 2. Visually resembling 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) whose thermal properties are to investigate, and virtual instruments (thermometer, chronometer, heat-flow sensor) or displays (data charts, blackboard).



Figure 2. ThermoLab

The student can use the objects with simple and direct manipulation: 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 or complex thermal interactions and perform experiments on heat and temperature, phase transitions and thermal equilibrium.

An overview of the **teaching sequence** is outlined in figure 3. The whole sequence is a combination of both lecture type and laboratory teaching. The sequence consists of 5 modules, as listed bellow, covering the total of thermal phenomena studied in Greek curriculum.

- Introduction to Thermal Phenomena
- Thermal equilibrium
- Calorimetry
- Propagation of Heat
- Phase transitions

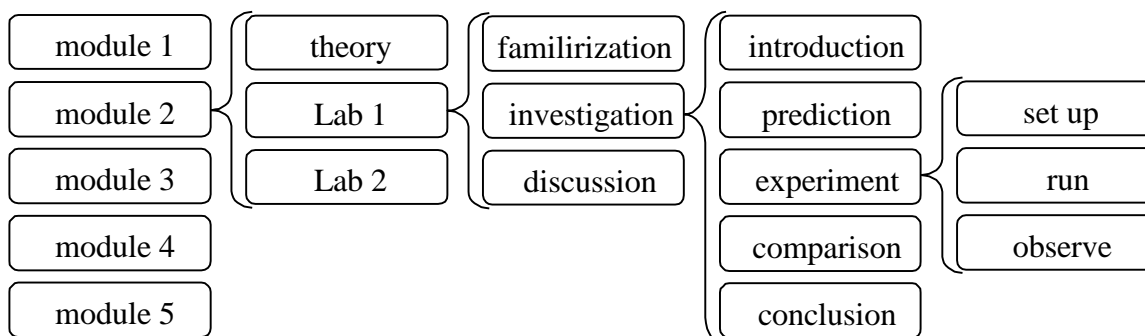


Figure 3. Example of the unfolding structure of the sequence (The cases of module 2 and Lab 1 are exemplary)

The design of the above TLS has two basic axes: (a) The use of ICT's and (b) the choice of thermal equilibrium as the key topic of the integration of the concepts. The first of the modules is introductory, to help students familiarize with the concepts and the laboratory sessions. In module 2, the "heat flow"

model is introduced, as a case of a two-body thermal interaction. The “heat flow” model was further elaborated in modules 3 and 4, and explored as a single-body case. Module 5 is conclusive.

Each module consists of theory (lecture type) and laboratory type sessions. Topics like the microscopic view of phenomena embedded in the curriculum were mainly addressed in lectures. In figure 3, we present the unfolded structure of one module. Laboratory sessions (as Lab-1, in fig.3) start with a familiarization phase, where contextualized everyday-life problems are presented to students. The TLS in the Lab sessions follows Open Learning patterns; students are engaged in a semi-structured discussion on the problem where investigation is a crucial part. Investigations, following the pattern of Predict-Observe-Explain (PEO), are carried out on the basis of structured worksheets, described below. Students conduct their experiments and compare the resulting data to their predictions. The ICT tools and tool integration, varies from one module to the other. MBL is found a very good tool to link between the real world phenomena and their graphic representation. This feature was mainly used in the introductory phase of each module. In Thermolab, on the other hand, students can very easily set up, conduct and rearrange the experiment, which means manageable parametric investigations. Besides several features proved to be very useful, where the ones that really show the “virtual” nature of Thermolab: Acceleration of time, the control of the room temperature (-20 to 130°C), the measurement of the heat transferred. We note particularly the ability to allow/stop thermal interactions, which provides for reflection on the running of experiments by students as well as real time graphing and multiple representations which add to the credibility of the environment for the students as extensively argued elsewhere (Squires, 1999; Petridou, 2005; Fournalari, 2004).

LAB SESSIONS IN THE TEACHING MODULES

As each module consists of lecture type and laboratory type sessions (figure 3), the sequence of modules results to a sandwich-like scheme, of alternating lecture and laboratory sessions. In Table I, we present the sequence of the modules, in reference to the topics and phenomena discussed and the ICT tools used in the lab sessions. ‘HON’ in Table 1 stands for conventional real world hands-on experiments, ‘MBL’ for Coach-based activities and SVL for ThermoLab activities.

As also stated previously, the design of the whole sequence is based on this choice of Thermal Equilibrium, as the key concept. With a series of phenomena where problems of two-bodies interaction was introduced, we aimed for the students to build step by step, a concrete core of explanations. These explanations include by default the concepts of heat and temperature. Main contribution was also accomplished by the use of the Calorimetry formula, which provides the single-body view of phenomena.

Table 1. Topics studied in each teaching module and Lab tools used.

Teaching modules	Topics - Phenomena	Lab Tools
Introduction to Thermal Phenomena	Thermometers & temperature measurement	HON + MBL
Thermal Equilibrium	Two bodies, same masses Two bodies, different masses One body /surroundings	MBL+SVL
Calorimetry	Different materials – liquid /liquid Different materials – liquid /solid	SVL
Propagation of Heat	Heat conduction Heat convection Heat radiation	HON+MBL +SVL
Phase transitions	Melting/ freezing Boiling, Evaporation/ condensation	MBL+SVL

A brief description of the laboratory sessions of the modules follows below.

Introduction to Thermal Phenomena

An introductory module was necessary for discussing the students' views and ideas about the phenomena. Historical matters were discussed, as well as the meaning of measurement in science generally. Another point was if objects always have the same temperature, or this can be changed. The students conducted experiments, with hot water that was getting cold, and measurements were taken with alcohol thermometers. For accreditation reasons, some measurements were also taken with MBL sensors, and this way the new tool was introduced.

Thermal Equilibrium

This is the core module where the concepts of heat and temperature that were previously discussed, are incorporated into a meaningful model of describing and explaining phenomena. Starting from the very simple and everyday problem of mixing two identical quantities of water with different temperature, students were involved in various two-bodies experiments, where different quantities of water of different temperature, in different beakers, were interacting when placed the one inside the other. The main task here was to estimate the final common temperature after thermal interaction. During these investigations, another tool was introduced, SVL; "Thermolab".

We consider this module to be the basis of the whole sequence, because during this, we intend for the students to be able to:

- a. Build a verbal explanation, making correct use of the terms heat-temperature, where they
- b. Define the temperature difference between the bodies as the cause of the heat flow,
- c. Determine the direction of the heat flow from the hotter body to the colder,
- d. Relate the amount of heat flowing with the difference in temperature of the bodies,
- e. Establish the concept of common temperature of the bodies after the interaction,
- f. Estimate qualitatively the final common temperature of the bodies, taking into account the role of the masses involved,
- g. Communicate the above in a graphic way.

In other words, students are given the basic characteristics of the explanatory model for thermal interactions. ThermoLab proved to be a major aid in most of the components of this model building process. One important feature is the option to inhibit the thermal interaction of the beakers with the surroundings, thus really investigate the two-bodies problem. In addition, the measurement of heat exchange and the real time graphic representation of it, provided information and visualization to the connection "bigger difference – greater flow". Such measurements are very difficult to be implemented in real laboratories. Very important case of investigations in this module is the one body - surroundings situation. We introduce it as being the upper limit of extension, a body of enormous mass.

Calorimetry

The calorimetry module as mentioned before is also important for the structure of the teaching sequence, because it provides another view of description of the phenomena, the one-body view. This means that after defining the temperature difference between two bodies, as the cause for heat flow from the hotter to the colder, the next step in building the explanatory model, is to model the amount of heat transferred. And this, in our sequence, is accomplished by focusing on the body that absorbs heat and by means of the Calorimetry formula. During this module, students work with two groups of investigations: a) Qualitative and b) semi-quantitative. For an extensive description of this module and students reactions in the parametric investigations see Petridou et al, 2005, in this volume.

Radiation

This module has two objectives: Firstly, to introduce radiation as one of the ways of heat propagation and to investigate the factors affecting it. During this, students are investigating the effect of the color of the body and the size of its external surface on the rate of heat radiation that is absorbed or emitted. Experiments are conducted with Coach and Thermolab, comparing black against white bodies and big against small (but of the same mass). The main concept to be handled here is that "a good absorber is also a good emitter" and vice versa. The second objective is to extend the two-bodies situations, to one

body – surroundings situation. As mentioned before, we introduce the latter as being the upper limit of extension, a body of enormous mass. Considering this, estimation of the final temperature in these cases of equilibrium is easy; it is the temperature of the surroundings. In either case, calculations of the heat transferred are made using the calorimetry formula. Once again we have to mention one important feature of Thermolab, the ability to allow (or not) the interaction between the bodies and the surroundings. But the really crucial feature for this line of investigations is the control of the ambient temperature, ranging from a very cold winter day (-20 °C) to the (unrealistic) burning summer day (130 °C). Although conditions in our investigations were limited to the range 10 – 90 °C, it was still very interesting to have a cold body (10 °C) absorbing heat in an extremely hot room (90 °C).

An interesting aspect of the investigations in this module is the splitting of the groups, so that half the students investigate e.g. a black body emitting, while the other half a black body absorbing heat radiation (figure 3). Results are announced to the whole class, in order that students come to a general conclusion.

An example of the ICT tools and tool integration for the module of radiation is outlined in figure 4.

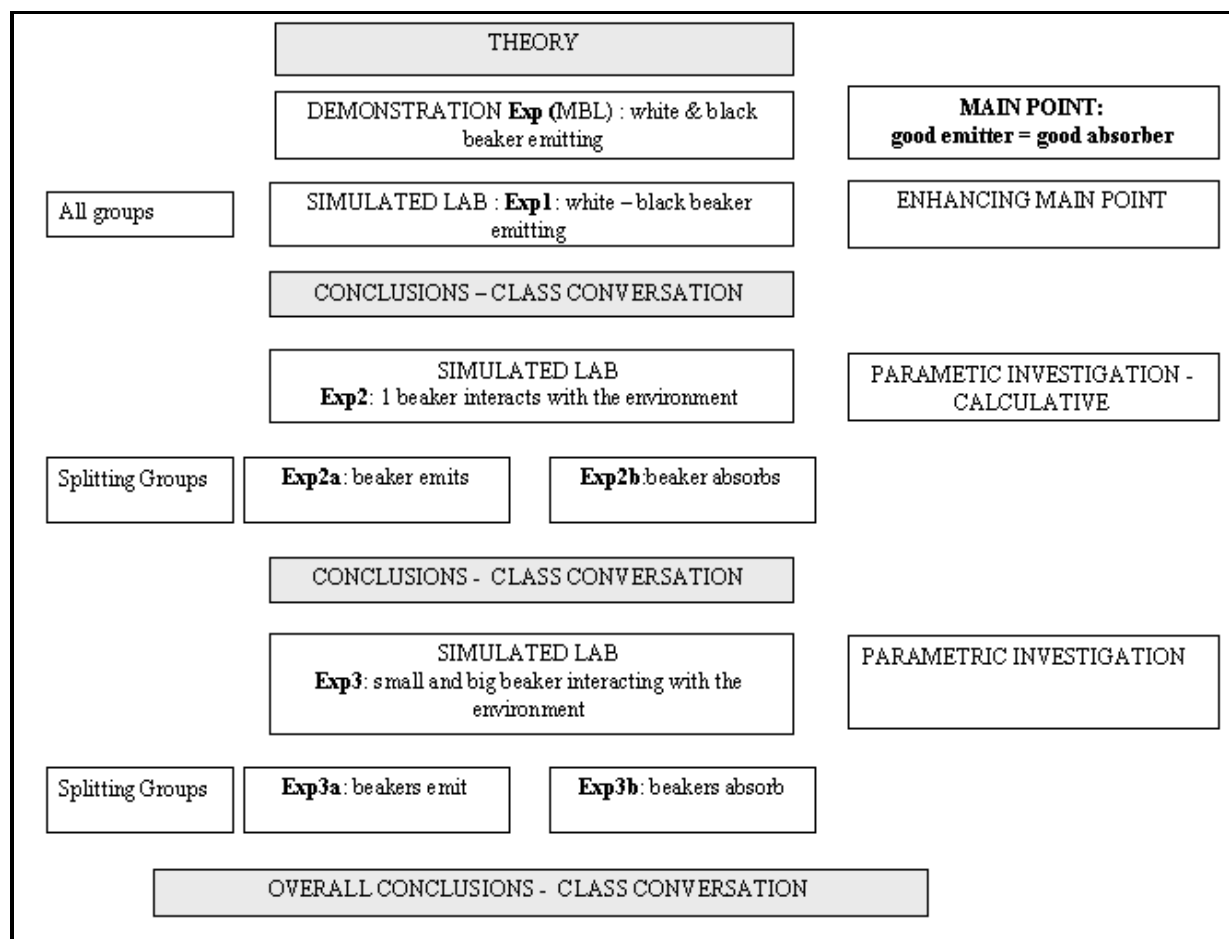


Figure 4. Detailed structure of the Heat Radiation module

Phase transitions

It is a kind of prototype approach to study phase transition phenomena through a two-body situation resulting to thermal equilibrium. Our idea thus, is to integrate phase transitions (melting/freezing of one of the bodies) and equilibrium investigations. The approach is qualitative, and students are asked to estimate the final temperature of equilibrium, taking in account the transition phase. This means that in a situation of two bodies of the same mass where one is going through a transition phase, the resulting common temperature after equilibrium is not in the middle of the initial ones, but is shifted towards the

initial temperature of the body that retains its phase. The role of real time graphing is very important in these investigations because the view of the “flat” line in the temperature graph during transition is the main point of our teaching.

STUDENTS WORKSHEETS

Students’ worksheets (WS) are designed on the basis of the P-E-O principals, as described bellow. Every worksheet includes information about the objectives, the materials and the assumed theoretical background. In some cases, they also include (at the end) activities with game-like characteristics, as a synopsis or as an extension of the topic under study. Wherever possible, collaboration activities are proposed, so as groups of students can interchange data, conclusions, or split the study of an experimental problem in parts (see figure 4, experiments 2 & 3).

The structure of the Worksheets (WS) is modular, consisting of various steps, like prediction, carrying out of the experiment, change of parameters, graph interpretation and conclusion. (Bisdikian & Psillos, 2002). In general, each WS refers to more than one experiment, including the following phases:

Phase 1: Students are introduced to the phenomena under study, usually by a kind of a qualitative problem to solve.

Phase 2: They express predictions about the evolution of the phenomena and the values of the quantities. In some cases, they draw the graph corresponding to their predictions

Phase 3: In order to test their predictions, students set-up and run an experiment, observe the evolution of the phenomena and the real-time graph. At this point, students are often asked to change the values of the parameters, make new predictions on the basis of their findings, and run again the experiment.

Phase 4-5: Students compare their predictions with the experimental results and graphs of previous phases and are guided draw conclusions.

Graphs are considered as the main connection between phenomena and the theory of Physics. So, the didactic use of ThermoLab is strongly based in interconnecting, of these two elements in the students’ perceptions. The set-up of the experiment (phase1) is aiming at the familiarization with the phenomena and the processes involved, for the smooth transition of the students to the execution of the experiments. The prediction (phase 2) indicates the starting perceptions of the students. Simulated experiments (phase 3) determine the level of abstraction in relevance of the scientific model and restrict the freedom of control, so as the students are focused on the manipulation of the parameters of the phenomena (phases 3-4). The comparison of the output graphs after the execution of the experiment with the ones in prediction phase and the capability of constructing new graphs after changing the values of the parameters (phases 4-5), may lead to the enhancement or the revision of the students’ perceptions.

CONCLUDING REMARKS

The evaluation of the TLS is still in process. The sequence was implemented to a class of students, in the 2nd year High school of compulsory education (13-14yrs). Students worked in pairs and for the laboratory sections an ICT lab was used. For the evaluation of the sequence, the teaching sessions were video recorded, personal paper & pencil tests were given in several points between the sessions, while 10 days after the completion of the sequence, each student was interviewed separately in a semi-structured type interview based on both paper & pencil and laboratory tasks. All the above data accompanied with the completed Work Sheets of each group, gave ground to some first comments, in tree axes that are presented below (see also Petridou et.al this volume).

- **Conceptual knowledge.** Students seem to realize main aspects of thermal equilibrium phenomena. They believe that bodies after thermal interaction have a common temperature and most of them are capable of estimating it, taking into account their masses or their material. The same applies for the case of bodies interacting with the surroundings. Positive results were also found in the investigations of thermal radiation phenomena. Students seem to realize the effect of color and

surface size to the heat radiated but most of all and the concept “good absorber is also good emitter”.

- **Graphing skills.** The students seem to relate graphs with phenomena of heating or cooling. The same applies to the reverse relation of phenomena to graphs.
- **Experimental skills.** Students seem to acquire certain skills of experimentation. They are capable of designing investigations by deciding the starting conditions, the magnitudes to be measured and drawing conclusions from the experimental data, in order to solve problems. Our findings also imply that these skills coming mostly from the use of ICT tools seem to be applicable from our students also in designing investigations using conventional experimental devices.

In concluding, this paper we note that the objective of extensive use of ICT based tools in the labs was to facilitate the enhancement of students’ understanding of the main concepts of heat as well as the development of their graphing and experimental skills. Since the TLS was aiming at high school, consideration had to be given to its applicability taking into account the guidelines and constraints of the physics curriculum. We consider that the TLS described above has a few interesting advantages. The use of caloric model and the emphasis on thermal equilibrium for the unified approach for most of the topics, gave students the opportunity to build a working model for the description and explanation of phenomena. Additionally, the integrated use of ICT tools used to support this approach proved to be of great aid. Real time graphing, easy manipulation of objects, the choice of cutting off the interaction with the surroundings and time acceleration are some of them.

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Ioannis Lefkos
PhD student
Dept. of Primary Education
Aristotle University of Thessaloniki
54006 Thessaloniki, GREECE
Email: lefkos@skiathos.physics.auth.gr

Dimitris Psillos
Professor
Dept. of Primary Education
Aristotle University of Thessaloniki
54006 Thessaloniki, GREECE
Email: psillos@skiathos.physics.auth.gr

Euripides Hatzikraniotis
Ass. Professor
Dept. of Physics
Aristotle University of Thessaloniki
54006 Thessaloniki, GREECE
Email: evris@physics.auth.gr