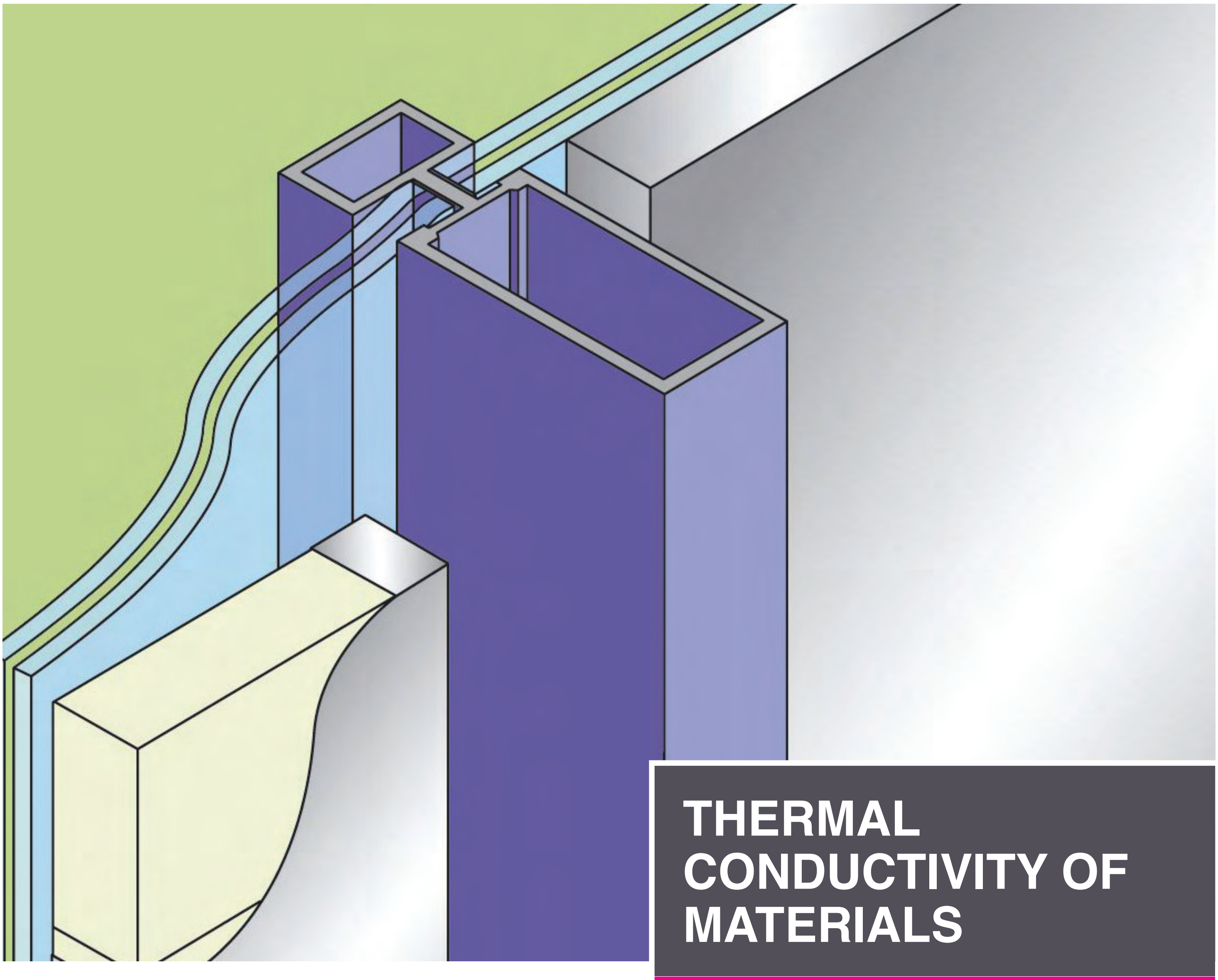

# THERMAL CONDUCTIVITY OF MATERIALS

## TEACHERS' MANUAL

*ORIGINAL VERSION*

# MATERIALS SCIENCE PROJECT

## UNIVERSITY-SCHOOL PARTNERSHIPS FOR THE DESIGN AND IMPLEMENTATION OF RESEARCH-BASED ICT-ENHANCED MODULES ON MATERIAL PROPERTIES

SPECIFIC SUPPORT ACTIONS

FP6: SCIENCE AND SOCIETY: SCIENCE AND EDUCATION

PROJECT COORDINATOR
CONSTANTINOS P. CONSTANTINOU,
LEARNING IN SCIENCE GROUP,
UNIVERSITY OF CYPRUS

PROJECT PARTNERS

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# THERMAL CONDUCTIVITY OF MATERIALS


**Design and development**

**University Team**
Psillos Dimitris
Hatzikraniotis Euripides
Molohidis Anastasios
Kallery Maria

**School Teachers**
Bisdikian Garabet
Axarlis Stelios
Taramopoulos Athanasios
Lefkos Ioannis
Petridou Eleni
Baltsios Spyridon
Goulis Vaggelis
Milioti Andromahi

**Software development**
Theodorakakos Antonis

***Other Contributors***
*Transfer, Implementation and Feedback*

**University Staff**
Gabriella Monroy
Sara Lombardi
Italo Testa

**School Teachers**
Cascini Emanuela
D'Ajello Caracciolo Gabriele
Montalto Giorgio
Salzano Imma

**Peer review and feedback**
Martine Meheut

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# A: TEACHER'S GUIDE

## 1. INTRODUCTION TO THE MODULE

The recently started European Project on Material Science aims at enhancing secondary students' understanding of scientific inquiry, increasing their interest in science and stimulating their appreciation of relevance of science and the relation between science and technology. In five countries groups are developing and implementing research-based teaching/learning sequences in educational contexts. A characteristic of this endeavor is its focus on investigating partnerships between university researchers and schoolteachers and on innovative approaches towards introducing aspects of Material Science at different levels in compulsory education. The Aristotle University of Thessaloniki group focuses on developing and investigating a module (or Teaching Learning Sequence, see further on) on the thermal properties of materials and specifically thermal conductivity for the lower grades of secondary school.

Several researchers and science educators support the view that the teaching of science as inquiry aims at enabling students to obtain experiences that are authentic with respect to the scientific experience. In teaching science as inquiry students are involved in investigative activities that give them the opportunity to actively construct concepts and models, which scientists use to intervene in and represent the natural world. Science teaching and learning deals not only with the acquisition of knowledge about models and theories but also with the development of procedures which enable students to carry out experimental investigations and apply scientific knowledge in the description and interpretation of physical phenomena. Understanding science implies also some understanding of the practices involved in scientific inquiry, aspects of which are essential for the teaching of scientific subjects to students. Such practices distinguish scientific literacy from other types of literacy.

Research findings support the teaching of science through inquiry and indicate that children at compulsory education should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with scientific inquiry, including skills such as conducting investigations, using appropriate tools and techniques to gather data, manipulate data, explore appropriate conceptual models, thinking about relationships between evidence and explanations and communicating scientific arguments (Minstrell & Van Zee, 2000, Windschitl & Thompson 2006, Flick & Lederman, 2006).

Teaching science as inquiry involves the transition from a teacher-centered pedagogy, which is often encountered in conventional classrooms, towards a more learner-centered one. We consider that the development of topic-oriented teaching learning sequences (TLS) is one approach towards introducing innovative inquiry-oriented instruction in conventional classrooms. This approach becomes more effective when the TLS develop gradually out of design and implementations according to an iterative cyclical evolutionary process enlightened by research data (for a review see Méheut & Psillos, 2004). The development of the present module follows this approach **so hereafter the terms module and TLS are used with the same meaning.**

Thermal phenomena, heating, cooling, and related scientific concepts, models and theories, is a topic area that educators and researchers consider challenging and age appropriate for primary and secondary education. It is included in most curricula worldwide in various versions depending on the context and the aims of teaching. Research (e.g. Kesidou, Duit & Glynn, 1995) has shown that students and to a certain extend teachers hold intuitive views about phenomena and concepts which are related to their everyday experiences. Students, in their explanations, face difficulties in differentiating the concepts of heat and temperature, do not take into account all the parts of an interacting thermal system, often neglecting the environment, especially the surrounding air. Students do not necessarily believe that objects that are in thermal contact will interact and tend towards thermal equilibrium and thus acquire the same temperature. This adds to the difficulties of understanding the idea of thermal equilibrium, and makes a scientific interpretation of the cause of heat transfer more difficult to accomplish.

Concerning conduction students seem to be broadly familiar with ideas such "heat movement, hotness movement, heat transfer" but also use "coldness movement". However, often either they do not focus on how heat transfer occurs or provide alternative explanations for transfer mechanisms in solids liquids and gases (Engel, Clough & Driver, 1985, Sciaretta, Stilli & Vicentini, 1990). Construction of unified views on what happens in conduction is prevented by disruptive everyday experiences, for example the contrast they feel between the cold sensation generated when they touch good conductors (such as metals, e.g. a pan) and the warm sensation they feel in touching insulators (such as the pan's wooden or plastic handle).

Research based innovative approaches in the topic of Heat and Temperature focus on helping students construct their understanding of the concepts heat and temperature and their differentiation (e.g. Thomaz et al. 1997); other researchers focus on helping students understand thermal equilibrium as a central organizing concept in this topic (Arnold & Millar, 1996). Clark & Jorde (2004) analyzed the impact of an integrated sensory model within thermal equilibrium visualizations. Linn and colleagues (1996) focused on students' integration of experiential and scientific concepts by employing a macroscopic heat flow model; however, Wiser & Amin, (2001) have argued that understanding microscopic mechanisms helps students to differentiate the concepts of heat and temperature. In most of these studies, in addition to usual experiments, ICT based materials have been used, such as simulated microscopic models, which have opened up new learning opportunities for the students.

Less is known about a comprehensive understanding of heat conduction which refers normally to heat transfer in solids without mass movement. A comprehensive treatment of thermal conductivity requires some understanding of the basic concepts of in the topic of heat as well as of factors and mechanisms involved in conduction. It is usually beyond the foci of compulsory education curricula. However, from the point of view of introductory Material Science conductivity is an essential property of natural materials and advanced technology artifacts. The field of application of this process is widespread and involves ceramics and polymers, metals and alloys composites and relevant natural or synthetic materials, artifacts and applications such as glasses, cooking devices, jackets, ceramic ovens, insulating styrofoams, to name only a few materials whose conductivity affects everyday experiences. From a social point of view, students and adults experience everyday phenomena related to conduction in situations like cooking, take decisions about using artifacts such as their jackets or come to familiarize themselves with several newly developed materials which, for example, affect heat losses in their house, school or work.

We consider that it is educationally significant and socially relevant to provide opportunities for students to become familiar with aspects of material science and specifically to engage in inquiry about thermal conductivity of materials, to extend their knowledge of basic concepts in the topic of Heat and construct their understandings in the context of contemporary technological applications. In this context we developed the present module which aims at enhancing students' understanding of conductivity. In the following we present essential design features as well as developmental process concerning this module.

Apart from the teachers and researchers who are referred to the contributors' page, without whom this project would not be feasible, I would like to thank my students Kyparissia Lytridou, Xrysanthos Sokratous, Ilya Hristodoulou, Eva Tziola for their contribution in collecting and developing materials; Dimitris Evagelinos for collecting data; Sinan Yakoup, Embluk Tayfun and Kapza Giouner, students of the Pedagogical Academy for Muslim Minority Teachers in Thessaloniki as well as Dafni Drakaki for handling data. Particularly I would like to thank Eleana Dalagdi for her continue work and contribution in the running of this project.

**Prof. Dimitris Psillos**
Group Leader Working Group
of Aristotle University of Thessaloniki

## 2. CONNECTION OF THIS MODULE TO OTHER MODULES IN MATERIALS SCIENCE PROJECT

Materials Science Project was initiated as an answer to the escalating problems observed in science education. The different educational systems across the European Community have to confront very similar types of problems. The most significant problem is the continuously decreasing number of students that wish to continue their studies in science. Another worrying phenomenon is the persistent gender gap that exists in the choice of specific science subjects, as well as in the advancement of the two sexes up the career ladder. Even though in other professions the gap has closed, in the science field remains constant. Finally, traditional teaching approaches that give emphasis on factual content and rote memorization are not leading to real lasting learning and as a consequence to future citizens that are scientifically literate. All these symptoms are in contrast to EU plans for sustainable growth and wider participation of the general public into decision making processes regarding complex and knowledge dependant issues.

Therefore, all the modules have a common base; they are innovative programs aiming at improving the quality of science teaching and learning in schools. To facilitate the required changes we need to (a) cultivate appreciation for the nature of science and scientific reasoning and (b) promote science teaching and learning approaches that follow closely the way science is done in authentic context.

The modules are the outcome of a close partnership between experienced science education researchers and science teachers. Each of the modules studies a different aspect of the broad area of Materials Science. The topic of Materials Science was selected due to the emerging technological advances and the lack of educational innovative ideas in this field. The design of the ICT enhanced modules is based on the inquiry activities; students design and carry out investigations in order to produce meaningful answers (evidence-based explanations). Inquiry method supplies students with knowledge and skills that are essential for living and working in the “information society”. Other similarities include strategies integrated in each of the modules (e.g. conceptual modeling, elicit-confront-resolve, predict-observe-explain, etc). These are not common in all the modules; different modules share different elements.

Thus, common elements to the whole project are:

- to address topics of basic physics through the study of materials and their applications
- to introduce innovative science instructional methods into primary and lower secondary school curricula as a means of supporting science learning as a process of inquiry. Promoting science culture and developing an understanding about the work of scientists
- to eventually contribute towards updating the Physics Curriculum with new, more interesting and more attractive topics and to help increase the number of students that decide to study science or to follow a career in science
- to motivate students to study science in order to understand the basic scientific principles involved in many applications (telecommunications, entertainment, sports, etc).

# 3. BACKGROUND SCIENTIFIC CONTENT

## 3.1. HEAT CONDUCTION

Conduction is heat transfer by means of molecular agitation within a material without any motion of the material as a whole. If one end of a metal rod is at a higher temperature, then energy will be transferred down the rod toward the colder end because the higher speed particles will collide with the slower ones with a net transfer of energy to the slower ones (Figure 3.1).

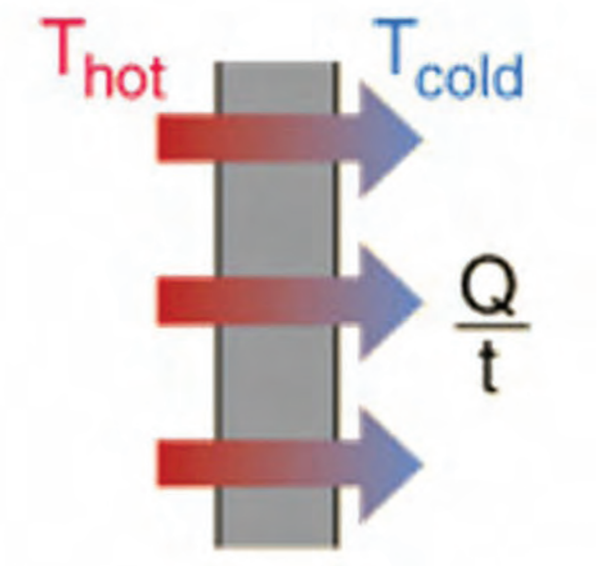



FIGURE 3.1: THE MECHANISM OF HEAT CONDUCTION

For heat transfer between two plane surfaces, such as heat loss through the wall of a house, the rate of conduction heat transfer is:

$$\frac{Q}{t} = \kappa \cdot \frac{A}{d} \cdot (T_{hot} - T_{cold}) \quad (1)$$

where:
**Q** is the heat transferred in time t
**κ** is the thermal conductivity of the barrier
**A** is the area of the barrier
$T_{cold}$, $T_{hot}$ are the temperatures at the two sides of the barrier
**d** is the thickness of barrier

## 3.2. THERMAL CONDUCTIVITY IN BRIEF

- Heat transfer in solids is done by conduction. Conduction is heat transfer by means of molecular agitation within a material without any motion of the material as a whole.
- For non-metallic solids, the heat transfer is viewed as carried out via lattice vibrations. The thermal conductivity in non-metallic solids depends on the density of the material. The thermal conductivity in metals mainly depend on the electrical conductivity of the material, through the Wiedemann-Franz Law:

$$\kappa = L \cdot \sigma \cdot T \quad (2)$$

where, σ is the electrical conductivity, T is the temperature and L is a constant of proportionality (the Lorentz number)

$$\kappa = \kappa_L + \kappa_e$$

- The total thermal conductivity in a solid has two contributions, namely, one that arises from the lattice ($\kappa_L$) and another that comes from the electrons ($\kappa_e$):

$$\kappa = \kappa_L + \kappa_e \quad (3)$$

## 3.3. THERMAL DIFFUSIVITY

In heat transfer we can distinguish between two extreme cases: the steady state and the transient state. The steady-state heat transfer analysis is used to determine temperature distribution, heat flow and heat flux in steady-state conditions. Transient heat transfer analysis predicts the outcome when temperatures on a part vary over time. In transient heat transfer, part of the heat is “consumed” in heating up the body (see Fig. 3.2)

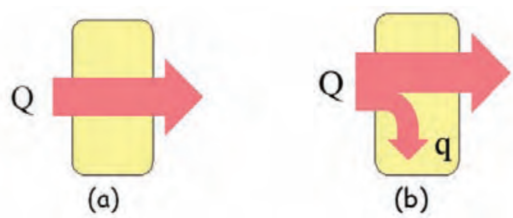



FIGURE 3.2: HEAT TRANSFER IN A STEADY STATE (A) AND IN A TRANSIENT STATE (B)

Thermal Diffusivity (α) is a measure of the rate at which a temperature disturbance at one point in a body travels to another point. It is associated with the propagation of heat into the medium during a change of temperature with time. The higher the thermal diffusivity is, the faster the propagation of heat into the medium. The rate at which heat spreads through an element, dependents upon: thermal conductivity κ, density ρ, and specific heat at constant pressure $C_P$. It is expressed by the relationship $\kappa/\rho.C_P$

For illustrative purposes consider this example. A rectangular block 50 cm long is initially at 100°C (see fig. 3.3). The temperature at one end is then dropped to 0°C. The temperature of the block will now vary with position and time.

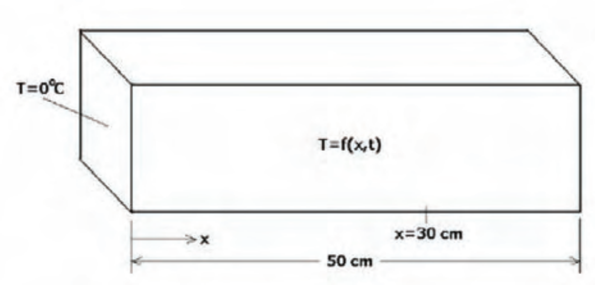



FIGURE 3.3: A SEMI-INFINITE MEDIUM UNDERGOING PURE CONDUCTIVE HEAT TRANSFER.

The time required for the temperature to be reduced to 50°C at a point 30 cm along the block is given for four materials in the following table:

As can be seen in the above table, the density (ρ) for the different materials is decreased from silver to glass, where the specific heat (Cp) is increased. These opposite trends cancel out, and thus, thermal diffusivity (α) is empirically found to be proportional to thermal conductivity (κ).

## 3.4. FURTHER READING

### 3.4.1. DEFINITIONS[1]

In physics and thermodynamics, **heat** (symbolized by Q) is any flow of energy from one body or system to another due to a difference in temperature. In thermodynamics, the quantity TdS is used as a representative measure of the (inexact) **differential heat** δQ, which is the absolute temperature of an object multiplied by the differential quantity of a system's entropy measured at the boundary of the object. Heat can flow spontaneously from an object with a high temperature to an object with a lower temperature. The transfer of heat from one object to another object with an equal or higher temperature can happen only with the aid of a heat pump. High temperature bodies, which often result in high rates of heat transfer, can be created by chemical reactions (such as burning), nuclear reactions (such as fusion taking place inside the Sun), electromagnetic dissipation (as in electric stoves), or mechanical dissipation (such as friction). Temperature is used as a measure of the internal energy or enthalpy that is the level of elementary motion giving rise to heat transfer. Heat can only be transferred between objects, or areas within an object, with different temperatures

MATERIAL PROPERTIES AT 300K AND TIME REQUIRED

| MATERIAL | SILVER | COPPER | STEEL | GLASS |
|---|---|---|---|---|
| Density, ρ ($kg/m^3$) | 10490 | 8960 | 7850 | 2580 |
| Specific heat, $C_P$ (J/kg.K) | 233 | 385 | 460 | 795 |
| Thermal conductivity, κ (W/m.K) | 427 | 386 | 48 | 0.8 |
| Thermal diffusivity, $\alpha \times 10^6$ ($m^2/s$) | 174 | 112 | 13.3 | 0.39 |
| Time | 9.5 min | 16.5 min | 2.2 h | 2 days |

1. *after http://en.wikipedia.org/wiki/Heat*

(as given by the zeroth law of thermodynamics), and then, in the absence of work, only in the direction of the colder body (as per the second law of thermodynamics). The temperature and phase of a substance subject to heat transfer are determined by latent heat and heat capacity. A related term is **thermal energy**, loosely defined as the energy of a body that increases with its temperature.

**Thermal energy** is a term often confused with that of heat. Loosely speaking, when heat is added to a thermodynamic system its thermal energy increases and when heat is withdrawn its thermal energy decreases. In this point of view, objects that are hot are referred to as being in possession of a large amount of thermal energy, whereas cold objects possess little thermal energy. Thermal energy then is often mistakenly defined as being synonym for the word heat. This, however, is not the case: an object cannot possess heat, but only energy. The term "thermal energy" when used in conversation is often not used in a strictly correct sense, but is more likely to be only used as a descriptive word. In physics and thermodynamics, the words “heat”, “internal energy”, “work”, "enthalpy" (heat content), "entropy", "external forces", etc., which can be defined exactly, i.e. without recourse to internal atomic motions and vibrations, tend to be preferred and used more often than the term "thermal energy", which is difficult to define.

Heat is related to the **internal energy** (U) of the system and **work** (W) done by the system by the first law of thermodynamics, $\Delta U = Q - W$, which means that the energy of the system can change either via work or via heat flows across the boundary of the thermodynamic system. In more detail, **internal energy** is the sum of all microscopic forms of energy of a system. It is related to the molecular structure and the degree of molecular activity and may be viewed as the sum of kinetic and potential energies of the molecules; it comprises the following types of energies.

- **Sensible energy**, the portion of the internal energy of a system associated with kinetic energies (molecular translation, rotation, and vibration; electron translation and spin; and nuclear spin) of the molecules.
- **Latent energy**, the internal energy associated with the phase of a system.
- **Chemical energy**, the internal energy associated with the atomic bonds in a molecule.
- **Nuclear energy**, the tremendous amount of energy associated with the strong bonds within the nucleus of the atom itself.
- **Energy interactions**, those types of energies not stored in the system (e.g. heat transfer, mass transfer, and work), but which are recognized at the system boundary as they cross it, which represent gains or losses by a system during a process.
- **Thermal energy**, the sum of sensible and latent forms of internal energy.

**Heat transfer** is the transition of thermal energy from a heated item to a cooler item. When an object or fluid is at a different temperature than its surroundings or another object, transfer of thermal energy, also known as heat transfer, or heat exchange, occurs in such a way that the body and the surroundings reach thermal equilibrium. Heat transfer always occurs from a hot body to a cold one, a result of the second law of thermodynamics. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed down.

Classical transfer of **thermal energy** occurs only through conduction, convection, radiation or any combination of these. Heat transfer associated with carriage of the heat of phase change by a substance (such as steam which carries the heat of boiling) can be fundamentally treated as a variation of convection heat transfer. In each case, the driving force for heat transfer is a difference of temperature.

- **Heat**, a transfer of thermal energy, (i.e., of energy and entropy) from hotter material to cooler material. Heat transfer may change the internal energy of materials.
- **Internal energy**, the internal vibrational energy that the molecules or electrons composing all materials contain (except at absolute zero).
- **Conduction**, transfer of heat by electron diffusion or phonon vibrations.
- **Convection**, transfer of heat by conduction in a moving medium, such as a fluid.
- **Radiation**, transfer of heat by electromagnetic radiation or, equivalently, by photons.
- **Phase change**, transfer of heat by the potential energy associated with the heat of phase change, such as boiling, condensation, or freezing.

### 3.4.2. TEMPERATURE

A convenient operational definition of temperature is that it is a measure of the average translational kinetic energy associated with the disordered microscopic motion of atoms and molecules. The flow of heat is from a high temperature region toward a lower temperature region. The details of the relationship to molecular motion are described in kinetic theory. The temperature defined from kinetic theory is called the kinetic temperature. Temperature is not directly proportional to internal energy since temperature measures only the kinetic energy part of the internal energy, so two objects with the same temperature do not in general have the same internal energy (see water-metal example).

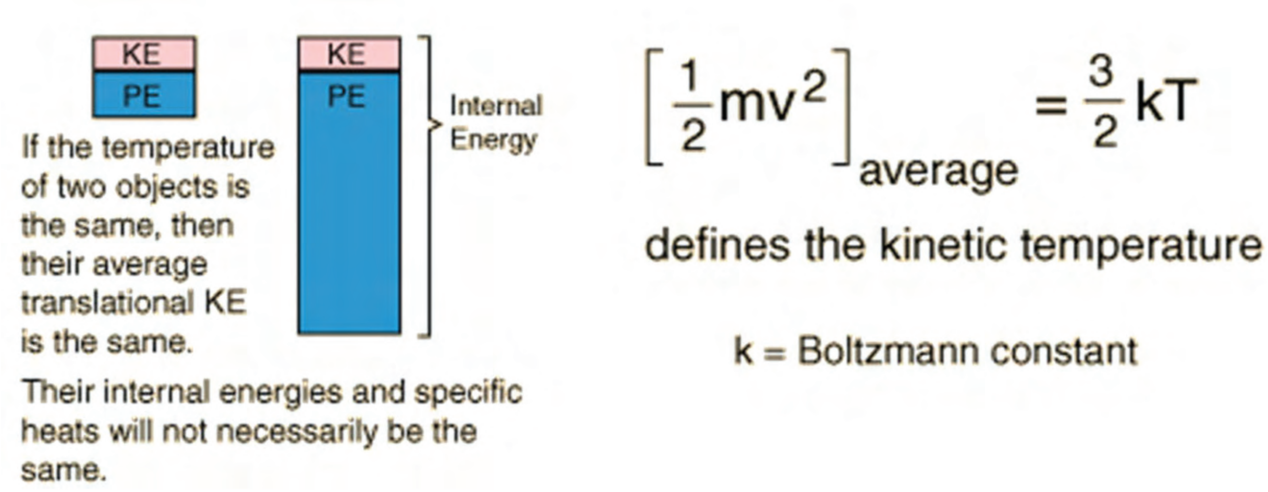



FIGURE 3.4: KINETIC AND POTENTIAL ENERGY

### 3.4.3. THERMAL CONDUCTIVITY

Heat transfer by conduction involves transfer of energy within a material without any motion of the material as a whole. The rate of heat transfer depends upon the temperature gradient and the thermal conductivity of the material. Thermal conductivity is a reasonably straightforward concept when you are discussing heat loss through the walls of your house, and you can find tables, which characterize the building materials and allow you to make reasonable calculations.

Conceptually, the thermal conductivity can be thought of as the container for the medium-dependent properties that relate the rate of heat loss per unit area to the rate of change of temperature.

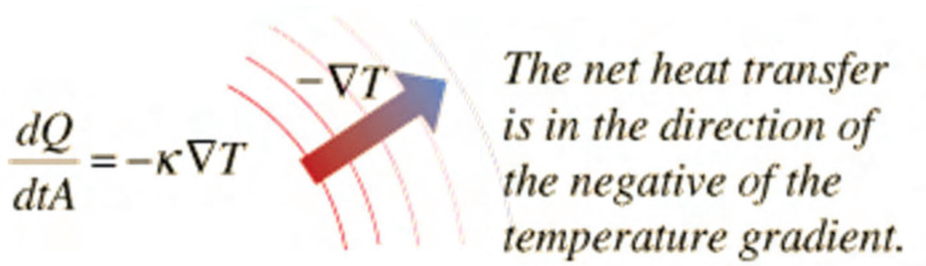



FIGURE 3.5: SCHEMATIC ILLUSTRATION OF THE HEAT TRANSFER

The mathematical gradient of a function is a directional derivative, which points in the direction of the maximum rate of change of the function. The direction of heat transfer will be opposite to the temperature gradient since the net energy transfer will be from high temperature to low. This direction of maximum heat transfer will be perpendicular to the equal-temperature surfaces surrounding a source of heat.

More fundamental questions arise when you examine the reasons for wide variations in thermal conductivity. Gases transfer heat by direct collisions between molecules, and as would be expected, their thermal conductivity is low compared to most solids since they are dilute media. Non-metallic solids transfer heat by lattice vibrations so that there is no net motion of the media as the energy propagates through. Such heat transfer is often described in terms of "phonons", quanta of lattice vibrations. Metals are much better thermal conductors than non-metals because the same mobile electrons, which participate in electrical conduction, also take part in the transfer of heat.

Conceptually, the thermal conductivity can be thought of as the container for the medium-dependent properties, which relate the rate of heat loss per unit area to the rate of change of temperature, as in equation (4).

$$\frac{\Delta Q}{\Delta t \cdot A} = \kappa \cdot \frac{\Delta T}{\Delta x} \qquad 4$$

where:

$\frac{\Delta Q}{\Delta t \cdot A}$ is the power per unit area transformed

κ is the thermal conductivity of the material

$\frac{\Delta T}{\Delta x}$ is the temperature gradient

### 3.4.4. THERMAL CONDUCTIVITY IN CRYSTALLINE SOLIDS

For an ideal gas the heat transfer rate is proportional to the average molecular velocity, the mean free path, and the molar heat capacity of the gas:

$$\kappa = n\frac{\bar{v} \cdot \lambda \cdot c_V}{3 \cdot N_A} \qquad 5$$

where:

κ is the thermal conductivity
n is the number of particles per unit volume
$\bar{v}$ is mean particle speed
λ is the particle mean free path
$c_V$ is the molar heat capacity
$N_A$ is the Avogadro's number

For non-metallic solids, the heat transfer is view as being transferred via lattice vibrations, as atoms vibrating more energetically at one part of a solid transfer that energy to less energetic neighboring atoms. This can be enhanced by cooperative motion in the form of propagating lattice waves, which in the quantum limit are quantized as phonons. Practically, there is so much variability for non-metallic solids that we normally just characterize the substance with a measured thermal conductivity when doing ordinary calculations.

### 3.4.5. THERMAL CONDUCTIVITY IN METALS

For metals, the thermal conductivity is quite high, and those metals, which are the best electrical conductors, are also the best thermal conductors. At a given temperature, the thermal and electrical conductivities of metals are proportional, but raising the temperature increases the thermal conductivity while decreasing the electrical conductivity. This behavior is quantified in the Wiedemann-Franz Law:

$$\kappa = L \cdot \sigma \cdot T \qquad 6$$

where:

κ is the thermal conductivity
L is the Lorentz number
σ is the electrical conductivity
T is the temperature

### 3.4.6. THE WIEDEMANN-FRANZ LAW

The ratio of the thermal conductivity to the electrical conductivity of a metal is proportional to the temperature. Qualitatively, this relationship is based upon the fact that the heat and electrical transport both involve the free electrons in the metal. The thermal conductivity increases with the average particle velocity since that increases the forward transport of energy. However, the electrical conductivity decreases with particle velocity increases because the collisions divert the electrons from forward transport of charge. This means that the ratio of thermal to electrical conductivity depends upon the average velocity squared, which is proportional to the kinetic temperature. The molar heat capacity of a classical monoatomic gas is given by

$$C_V = \tfrac{3}{2}R = \tfrac{3}{2}N_A \cdot k_B \qquad 7$$

where:

$C_V$ is the molar heat capacity

$N_A$ is the Avogadro's number
$k_B$ is the Boltzmann's constant

Qualitatively, the Wiedemann-Franz Law can be understood by treating the electrons like a classical gas and comparing the resultant thermal conductivity to the electrical conductivity. The expressions for thermal and electrical conductivity become:

$$\kappa = n\frac{\bar{v}\cdot\lambda\cdot k_B}{2} \qquad \sigma = n\frac{\lambda\cdot e^2}{m\cdot\bar{v}} \quad (8)$$

THERMAL CONDUCTIVITY — ELECTRICAL CONDUCTIVITY

where:
e is the electron charge
m is the electron mass
while the rest symbols have the meaning of equations 5, 6 and 7.
Using the expression for mean particle speed from kinetic theory

$$\bar{v} = \sqrt{\frac{8\cdot k_B T}{\pi\cdot m}} \quad (9)$$

the ratio of these quantities can be expressed in terms of the temperature. The ratio of thermal to electrical conductivity illustrates the Wiedemann-Franz Law

$$\frac{\kappa}{\sigma} = \frac{4\cdot k_B^2}{\pi\cdot e^2}T = L\cdot T \quad (10)$$

While qualitatively agreeing with experiment, the value of the constant is in error in this classical treatment. When the quantum mechanical treatment is done, the value of the constant is found to be:

$$L = \frac{\kappa}{\sigma\cdot T} = \frac{\pi^2\cdot k_B^2}{3\cdot e^2} = 2.45\cdot 10^{-8}\frac{W\cdot\Omega}{K^2} \quad (11)$$

This is in good agreement with experiment. The fact that the ratio of thermal to electrical conductivity times the temperature is constant forms the essence of the Wiedemann-Franz Law. It is remarkable that it is also independent of the particle mass and the number density of the particles.

### 3.4.7. TOTAL THERMAL CONDUCTIVITY

Total thermal conductivity has thus two contributions, namely, one that arises from the lattice (eq. 5) and another that comes from the electrons (eq. 6).

$$\kappa = \kappa_L + \kappa_e \quad (3)$$

where:
$\kappa_L$ is the lattice contribution to thermal conductivity
$\kappa_e$ is the electronic part of the thermal conductivity

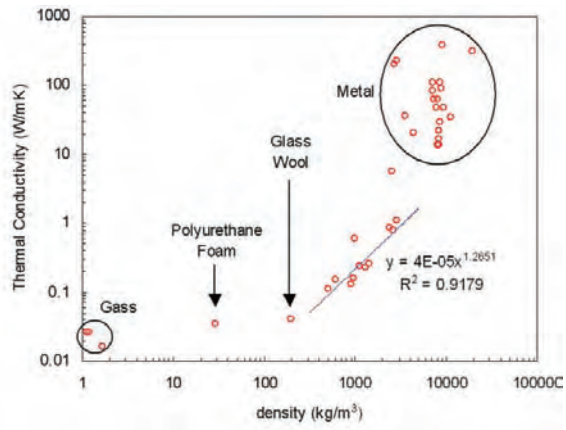



FIGURE 3.6: THERMAL CONDUCTIVITY VS. DENSITY FOR DIFFERENT MATERIALS

In metals the thermal conductivity due to the heat conduction of electrons is by far more significant to the one that arises from the lattice term. In insulators, on the other hand, the lattice contribution to thermal conductivity is the dominant part.

### 3.4.8. ON THE ORIGIN OF THERMAL CONDUCTIVITY

The thermal conductivity of a system is determined by how atoms comprising the system interact. There are no simple, correct expressions for thermal conductivity. There are two different approaches for calculating the thermal conductivity of a system.

The **first approach** employs the Green-Kubo relations. Although this employs analytic expressions which in principle can be solved, in order to calculate the thermal conductivity of a dense fluid or solid using this relation requires the use of molecular dynamics computer simulation.

The **second approach** is based upon the relaxation time approach. Due to the anharmonicity within the crystal potential, the phonons in the system are known to scatter. There are three main mechanisms for scattering:

- Boundary scattering, a phonon hitting the boundary of a system;
- Mass defect scattering, a phonon hitting an impurity within the system and scattering;
- Phonon-phonon scattering, a phonon breaking into two lower energy phonons or a phonon colliding with another phonon and merging into one higher energy phonon.

In physics, **a phonon** is a quantized mode of vibration occurring in a rigid crystal lattice, such as the atomic lattice of a solid. The study of phonons is an important part of solid state physics, because phonons play a major role in many of the physical properties of solids, including a material's thermal and electrical conductivities. In particular, the properties of long-wavelength phonons give rise to sound in solids - hence the name phonon from the Greek φωνή (phonē) = voice. In insulating solids, phonons are also the primary mechanism by which heat conduction takes place.

Phonons are a quantum mechanical version of a special type of vibrational motion, known as normal modes in classical mechanics, in which each part of a lattice oscillates with the same frequency. These normal modes are important because, according to a well-known result in classical mechanics, any arbitrary vibrational motion of a lattice can be considered as a superposition of normal modes with various frequencies; in this sense, the normal modes are the elementary vibrations of the lattice. Although normal modes are wave-like phenomena in classical mechanics, they acquire certain particle-like properties when the lattice is analyzed using quantum mechanics (see wave-particle duality.) They are then known as phonons.

Due to the connections between atoms, the displacement of one or more atoms from their equilibrium positions will give rise to a set of vibration waves propagating through the lattice. One such wave is shown in the figure below. The amplitude of the wave is given by the displacements of the atoms from their equilibrium positions. The wavelength λ is marked (fig. 3.7).

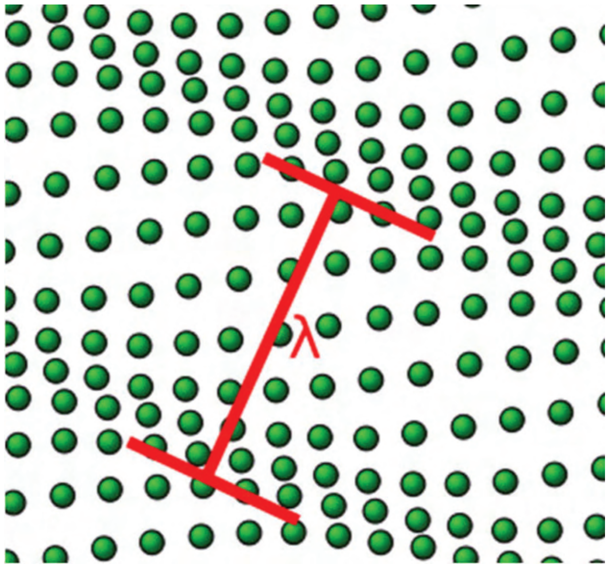



FIGURE 3.7: DEFINITION OF λ, THE PHONON WAVELENGTH

## 4. PRIOR KNOWLEDGE OF STUDENTS

In the Greek curriculum, the chapter on **Heat** is taught at the 2nd of Gymnasium (students aged 13 to 14). The teaching of heat is scheduled after the middle of the academic year. Before heat, **Mechanics** is taught, where among others, topics on **motion and kinetic energy** are dealt with.

Overall the curriculum on heat consists of three chapters: Heat, Phase Transitions, and Heat Transfer. In the 1st chapter, the main concepts introduced are: temperature, heat (as a form of energy), thermal equilibrium and specific heat. The chapter ends with an attempt to measure heat using the law of calorimetry and the introduction of microscopic aspects of temperature and heat. The present module assumes that students have been taught the first chapter or an equivalent topic, and have some slight familiarization with hands on experiments. Also in the participating schools students were involved in virtual experiments by using the Thermolab environment (see §6.II.1 and §7.5).

In brief, we assume that before this module should have some understanding of heat and temperature and their differentiation. Specifically:

- Students should recognize and measure the existence of a temperature difference in various objects.
- Students should understand that temperature difference causes heat flow from the hot to the cold object.
- Students should be able to recognize and describe everyday heating and cooling situations in terms of heat flow[2] and corresponding temperature change as well as recognize situations of thermal equilibrium involving several objects.
- Students should have some familiarization with hands on and virtual experimentation.
- Students should have some familiarization with graph reading and interpretation.

These objectives were realized by:

a) carrying out real experiments in groups (e.g. sensing heat by immersing a finger into hot/lukewarm/cold water, sensing heat by touching marble/wood/ carpet) or watching demonstration experiments (heating of water in a paper container); and

b) using the Thermolab software suite and namely its three virtual labs on the topic of "Heat and Temperature" (where the parameters of mass and heat flow are explored) and labs 1, 2, 4, 5 and 6 of the topic "Thermal Equilibrium - Part II" (involving the thermal interaction between quantities of water with varying masses or varying temperatures).

2. *E.g. to state that "the flame of the gas burner (or the ceramic heat plate of an electric stove) has higher temperature than the water being heated up. This causes a flow of heat from the hot body (gas burner or stove plate) to the warm one (water)".*

## 5. AIMS OF THE MODULE

The module aims at facilitating students to construct a deeper understanding of thermal conductivity of materials than it is normally taught in, at least the Greek Curriculum. At the same time the module makes use of heat conduction as a topic through which students who are used to traditional teaching will be introduced and experience teaching and learning of science as inquiry. In the design of the module it has been taken into account that both teachers and students are normally familiar with traditional transfer of knowledge approaches rather that inquiry ones.

This topic deals with materials and phenomena that are common, affect everyday life and can be studied at different levels. Students study thermal conductivity in a range of conductive and non conductive materials from different perspectives. It is innovative that students focus initially on heat conduction in ceramics and metals which are important distinctive cases of materials in terms of conductivity and afterwards well ahead in the sequence discuss the broad categories of conductors and insulators. Usual approaches in Greece and elsewhere discuss first the broad categories of conductors and insulators and then move to study specific cases of materials.

At the phenomenological level students carry out experimental investigations, make observations and handle situations that are familiar to them and gradually design their own approaches to study experimentally a problem. At the microscopic level they explore and play with microscopic didactically transposed models of metals and ceramics. These models are not constructed by the students but they are provided to them in order to explore their function for describing and interpreting conduction. Besides, they provide the framework for introducing students to the nature of models and learn about models and their function in science. Several applications of insulating and conductive materials provide a framework for generalizing about conductivity, link their knowledge with interesting applications and motivating students to study this topic. In particular the energy saving house is discussed towards the end of the module and provides a scenario in which students are prompted to work out suggestions for preventing heat loss.

The module is not introductory to the topic of heat and temperature but it's designed as an extended theme which may be used by the teachers in a flexible time zone during curriculum activities. Such flexibility is often part of the curricula including the Greek one.

In this context the present module aims at improving students' conceptual and epistemological understandings as well as enhance investigative skills. Students after completing this module should:

- understand that some materials allow heat to be conducted much faster than others. These materials are better heat conductors.
- be able to rank materials according to their thermal conductivity.
- understand that heat can be conducted through a thermally insulating material - realize the role of time.
- understand that heat flow takes place between bodies and their environment until these come to a thermal equilibrium with their environment.
- relate several factors which affect thermal conductivity. In particular for heat transfer between two plane surfaces, such as heat loss through the wall of a house, the rate of heat conduction is influenced by factors such as the area of a barrier, the temperature difference at the two sides of the barrier, the thickness of barrier and certainly the material of a barrier.
- understand that raise of the temperature of an object results in agitation of its particles due to the increase of their kinetic energy.
- interpret and compare thermal conduction in ceramic materials and in metals at the microscopic level.
- be able to explore and compare simulated microscopic models in ceramics and in metals.
- have some understanding of the nature and use of models in science.
- be able to draw on the use of conductors and insulators in house and everyday situations and for saving heat loss.
- have some skill to carry out an experimental investigation by simulated or hands on experiments.
- have some skill in searching the web about materials and their thermal conductivity.
- have some skill to plan an experimental investigation to verify or reject a hypothesis.
- have some familiarization with using experimental

evidence to decide on an everyday problem.

- be motivated to study science in order to understand the basic scientific principles involved in many applications

An overview of the suggested structure of the module is provided below. All units are expected to take place in one teaching hour.

| | |
|---|---|
| **UNIT 1** | Students study experimentally thermal interaction between quantities of water having the same temperature in cups made of different materials, during their cooling down and rank the materials used, according to their thermal conductivity. Reflect about their experimental activities. |
| **UNIT 2** | Students explore microscopic simulated models for temperature in ceramics and metals, compare different representations of models, search in the web for other representations of microscopic models and reflect on the function of simulation for understanding heat transfer. |
| **UNIT 3** | Students explore the role of the oscillation of particles of the lattice in thermal conduction in ceramics and in metals as well as the role of movement of free electrons in thermal conduction in metals. They use models to visualize and interpret heat conduction and reflect and learn about the function and use of models in science. |
| **UNIT 4** | Students study experimental techniques such as use of thermographic paper to detect heat conduction, design experimental investigations, are involved in hands on experimentation and rank metallic rods according to their thermal conductivity. The use of conductors in house and everyday situations is discussed. |
| **UNIT 5a** | Students study conductivity in ceramics and the role of density of materials in effecting heat conduction. They are engaged in experimental planning and discus the use of insulating material in everyday situations. |
| **UNIT 5b** | Students continue to study thermal conductivity in ceramics, design an experimental procedure to investigate the relationship between density and conductivity in ceramic materials and choose appropriate insulating material for a specific purpose. |
| **UNIT 6** | Students carry out an investigation in simulated lab on how the size of the thickness of walls of a vessel affects conduction; discuss the role of surface area. They reflect on experimental design for investigating several factors affecting conduction. |
| **UNIT 7** | Students discuss and reflect on taught knowledge and aspects of inquiry, discuss several insulating and conducting materials, are acquainted with synthetic materials and applications in house. |
| **UNIT 8** | Students apply their knowledge and skills to study and reduce thermal loss in an energy saving house. |

# 6. PEDAGOGICAL APPROACH AND CONTEXT

## I. TEACHING SCIENCE AS INQUIRY

Several researchers and research projects (Millar & Osborne, 1998) suggest that science education should aim at delivering to students' useful scientific knowledge by developing their understanding of representations of the material world. Students should understand how scientists represent the world in terms of concepts and models and how to use these models in approaching everyday needs. But science, apart from representations of the world, involves ways of intervening in the world by putting things to work in the laboratory according to theories and models. This kind of laboratory-centered interventionist practice supports theoretical productions and distinguishes scientific literacy from other types of literacy (e.g. philosophical or literary).

Science teaching and learning deals not only with the acquisition of knowledge about models and theories but also with the development of procedures which enable students to carry out experimental investigations and apply scientific knowledge in the description and interpretation of physical phenomena. Understanding science implies also some understanding of the practices involved in scientific inquiry, aspects of which are essential for the teaching of scientific subjects to students.

Several ideas have been expressed as to what science education for students should comprise and how it should be approached. Quite recently, science educators have investigated ways to improve the linking of theoretical models to practical activities by engaging students in labwork activities which develop both conceptual and procedural knowledge. A number of proposals focus on teaching of science through inquiry which aim at enabling students to obtain experiences that are authentic to scientists' experiences and is thought to make their learning more meaningful and to improve their scientific understanding (Minstrell & Van Zee, 2000, Windschitl & Thompson 2006). While earlier efforts to teach science as a process of inquiry have not always been successful, we can draw hope for improvement of this situation, from important advances in cognitive science, powerful teaching strategies and the contributions of information technology in the form of teaching and learning tools (Flick & Lederman, 2006).

Inquiry is considered by science educators as a major area of interest in students' education in science. Research findings support the teaching of science through inquiry and indicate that children at compulsory education should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with scientific inquiry, including skills such as conducting investigations, using appropriate tools and techniques to gather data, manipulate data, explore appropriate conceptual models, thinking about relationships between evidence and explanations and communicating scientific arguments.

Constructive approaches to inquiry may involve students in hands-on activities that are more inductively oriented, as in earlier efforts, as well as in minds-on creative activities such as exploration of conceptual models, co-ordination of the relationship between evidence and explanations, reflection and communication of scientific arguments (White & Frederiksen, 1998). Besides teaching science as inquiry involves the transition from a teacher-centered pedagogy, which is often encountered in conventional classrooms, towards a more learner-centered one. In this context, our TLS was designed to include a structured series of guided investigative tasks based on integration of hands-on experiments, simulated experiments and microscopic model simulations.

## II. DEVELOPING AN ENRICHED LEARNING ENVIRONMENT

### II.1. COMBINING REAL AND SIMULATED EXPERIMENTS

Traditionally school experiments on thermal phenomena are thought as 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, for the interpretation of the phenomena. Moreover, in a school hands on laboratory, students often 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 inquiry skills. 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 apparatuses (Psillos & Niedderer, 2002). In this context we opted to develop an enriched learning environment using traditional and promising ICT technology in order to provide rich opportunities for students to engage and make sense out of inquiry activities (Doerr, 1997).
We note that in the present text the term *virtual laboratory / experiment and simulated laboratory / experiment* are used with the same meaning.

The macroscopic observations are carried out by real (hands-on) experiments as well as simulated experiments, while the microscopic models are visualized by parametric simulations. As an example, one of the real lab experiments consists of a heated metal rod on which small balls are attached with wax. As heat propagates though the rod, the wax melts and the balls start to fall one by one. Virtual experiments have been effective in science teaching (Klahr, Triona & Williams, 2007), can hinder the slow nature of thermal interactions, allow experimenting in "extreme" conditions and easy manipulation of variables. Thus, the approach of combining real and virtual experiments may provide an integrative experiential basis suitable for inquiry-oriented learning, as inquiry refers to posing questions, making observations, designing investigations, collecting information, analyzing and interpreting data and constructing and communicating explanations.

The Flash simulations for simulated labs (shown in Figure 6.1) are parametric simulations of real experiments. The student is asked to set up the experiment by clicking on the virtual instruments according to a virtual teacher's instructions. The time, temperature, and a zoom in the beaker's wall are shown in the three circles on the left-most side of the simulation. A red arrow indicates the rate of the heat transfer from the inner beaker to the outer, which is dimmed upon the value of heat transfer.

In preliminary teaching before the module teachers use ThermoLab which is an open learning

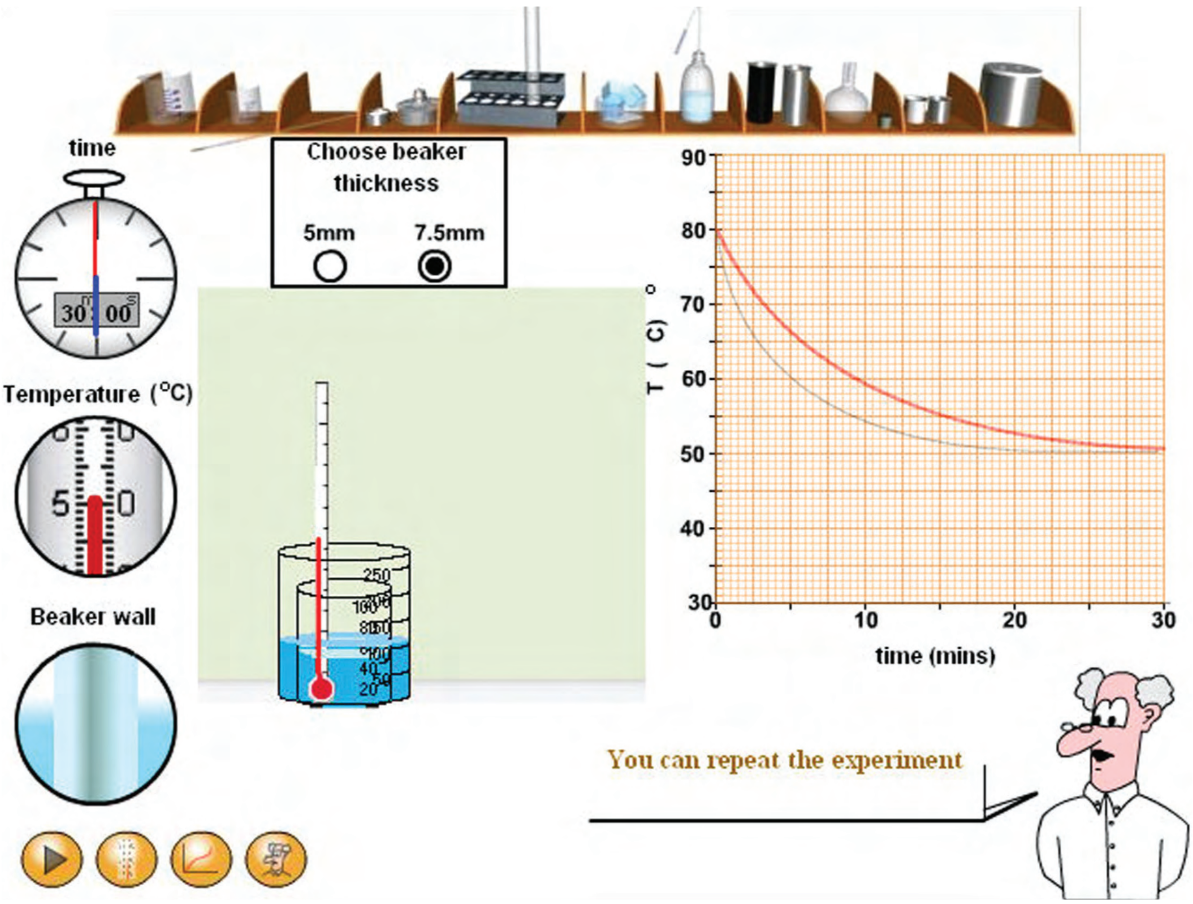



FIGURE 6.1: TYPICAL SCREEN SHOT FOR A SIMULATED LAB.

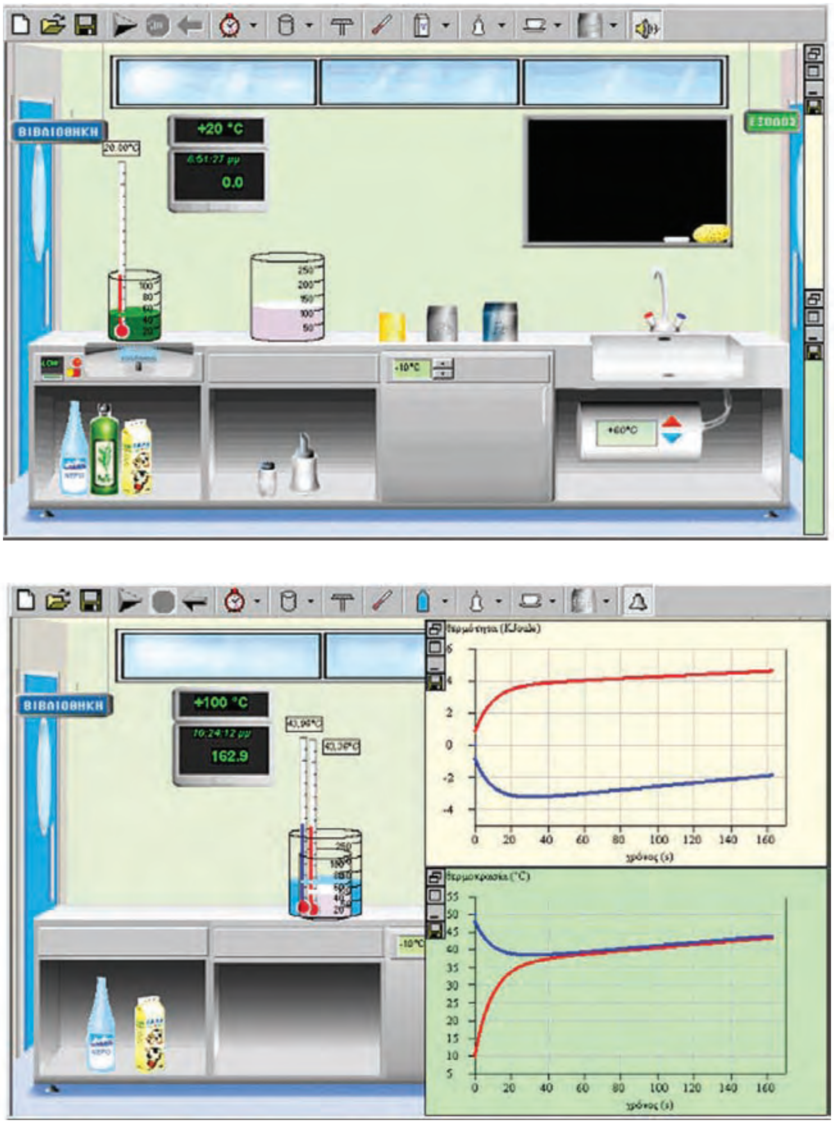



FIGURE 6.2: THERMOLAB SCREENSHOT OF TWO GLASS BEAKERS AT DIFFERENT INITIAL TEMPERATURE

environment suitable for studying thermal phenomena (Hatzikraniotis et. al, 2005). A typical screen shot for the Thermolab is presented in Figure 6.2. Visually resembling a real-world laboratory, it consists of a working bench on which experiments can be performed with 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 including real time graphs . 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.

## II.2. MICROSCOPIC MODELS AS TEACHING TOOLS

Research studies point out the significance of models as teaching tools and their potential to contribute in students' cognitive progress (France 2000, Saari & Viiri 2003, Crawford & Cullin 2004, Justi & Van Driel 2005) and in effective learning. Models and the process of scientific modeling are core components of scientific inquiry. Instructional approaches that are grounded on the premises of modeling-based learning engage students in the authentic practice of using models as tools for visualization, explanation and prediction. When a model is used for visualization contains characteristics of the object that represents, it looks and/or functions like it, when the model is used for explanation contains essential characteristics that help the understanding of the phenomenon and when it is used for prediction helps the user to check his hypothesis and predict the phenomenon. An area of concern relates to the long-standing didactical problem of the effective use of microscopic models by teachers and students to explain and predict physical phenomena in school topics such as thermal conduction and electrostatic interactions.

Literature suggests that visualized models are effective in supporting students' identification of "how things work". In the module, at the microscopic level, specially developed simulated particulate models are employed for visualizing conduction in ceramics and metals that depict thermal interactions in iconic, graphic and symbolic forms (Papageorgiou et. al., 2008). Flash simulations were developed for microscopic models one example of which is shown in Figure 6.3. It consists of a set of rigid balls arranged in a matrix form to simulate the lattice. The balls are vibrating with small or larger amplitude according to the temperature. Students are asked to observe the vibrational motion of the balls as the temperature rises. In the final part on this simulation, students can compare heat transfer in both metals and ceramics and link it to existence and movement in metals. The development of the microscopic simulations is based on a number of assumptions which are stated in section 7.4.3.

### II.3. REAL TIME GRAPHS

Graphical representation can be considered as a bridge facilitating the linking between physical phenomena and the related content theory during any data handling process connected to school science laboratory work. By introducing real-time data acquisition from real or simulated phenomena, the relation of content theory with physical phenomena seems to be placed on a new potential basis. The capacity of computers to construct real-time graphs in parallel with the evolution of phenomena can help graphing skills development and content knowledge acquisition (Linn et al. 1991). Graphical representations become a dynamic instrument (Bisdikian & Psillos, 2002). In the module real time graphs in the simulated labs provide for conceptual bridges to help students scaffold links between observations of thermal conduction and relevant models.

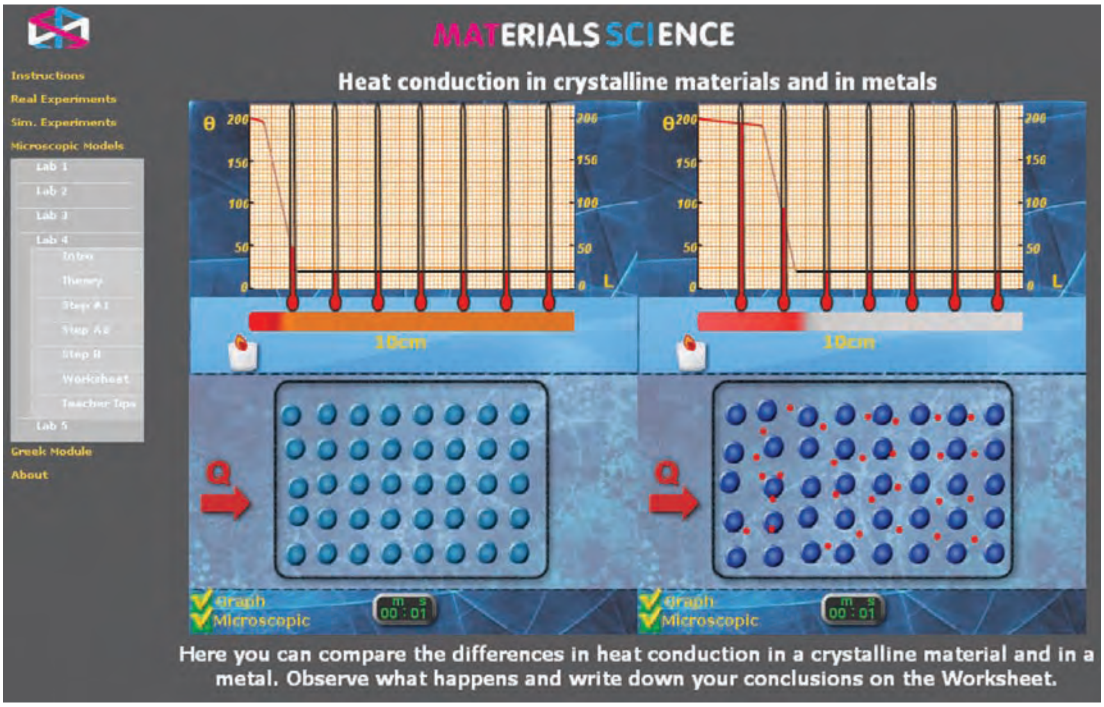



FIGURE 6.3: THE EFFECT OF ELECTRONS IN THE HEAT TRANSFER.
(TYPICAL SCREEN SHOT FOR A MICROSCOPIC MODEL)

## II.4. USE OF WEB BASED RESOURCES

Web based affordances provide for powerful and rich resources which may be available to students either for free or guided exploration. Guided exploration has the advantage of leading students to resources which have a visible link with the themes under study and avoiding endless search. In the TLS, Web based activities have been used in order to familiarize students with a variety of applications concerning conductivity in advanced technology materials as well as in with different representations of taught models.
For example: Extract from "Unit 2":

> 5.5 You can find some more information about ceramics in the internet, e.g. in www.wikipedia.org, ask for "ceramic materials" and then link to "glass" and then "amorphous". You can find details about glass and the structure of the particles in the lattice.
>
> You can also google the «Amorphous solid» and observe the images of the structure of the glass (see link to e-education.psu.edu, britannica.com, steelguru.com).
>
> Does this structure of the particles in the glass lattice look like the one you have met in your Worksheet? Why do you think this happened? Which are the advantages and disadvantages of our representation?

## III. A VARIETY OF GUIDED INQUIRY ACTIVITIES

Our TLS was designed to include a structured series of guided investigative tasks based on a variety of resources as mentioned above as well as of investigative activities like experimental investigations and model exploration. It should be noted here that our students who are usually taught science in a traditional 'transfer of knowledge' mode are gradually introduced to experimentation and model exploration through the activities included in their worksheets.

Guidance to students' investigative activities is provided by structured worksheets and teacher coordination. The WS are the core of the didactical activities in the 6 units of the module. The rest two are more teacher based. Worksheets provide guidance for students as well as teachers who may not expected to be familiar with investigative activities. In general, each WS refers to several student activities. The structure of the Worksheets (WS) is modular, consisting of various steps, like prediction, carrying out of the experiment, data interpretation and conclusion. Collaborative activities are proposed, in order for the students to share and interpret data, discuss specific questions of the worksheets and reach conclusions.

### III.1. EMPLOYING THE PREDICT-OBSERVE-EXPLAIN (POE) STRATEGY

Some Units, like Unit 1, are based on laboratory type sessions in which students interact with hands on or simulated experiments and make macroscopic observations. The Predict-Observe-Explain strategy is applied in such WorkSheets which is a very powerful strategy. POE typically involves: (i) a situation, asking for a prediction about what will happen when a change is made, and getting reasons for the prediction, (ii) performing the change and getting observations and (iii) attempting to reconcile any conflict between prediction and observation. The POE strategy enable learners to understand, monitor and evaluate inquiry activities and learning process. Strategies like Predict-Observe-Explain (POE), among others, provide students with a framework to guide their thinking. These strategies are important not only because they may improve students' conceptual understanding and problem solving abilities but also because they may develop significantly students' metacognitive abilities.

The Predict Observe Explain pattern is embedded in a number of the worksheets. Prediction elucidates students' ideas. The comparison of the results after the execution of the experiment with the ones in prediction phase may lead to the enhancement or the revision of the students' ideas. In the case of simulated experiments these 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. An indicative structure, which may be repeated throughout one unit, is as following is the following:

| | |
|---|---|
| **PHASE 1** | Students are initiated to the phenomena under study, often by engagement in a qualitative problem. The problem to be solved usually comes from everyday experiences, in order to be meaningful for the students.<br><br>**For example, from the worksheet 6** which focus on thickness as a factor that affects heat transfer, the everyday experienced problem is: *Your mother left on the stove the milk she was preparing for your breakfast, a little more time than usual. In order to cool it down quickly, she poured it from the initial glass, which had thin walls, into a same size glass, having thicker walls. She believed that this way the milk should cool down faster. Do you agree or disagree with her action? Why?* |
| **PHASE 2** | Students are prompted to elucidate their views and make predictions about the evolution of the phenomena. |
| **PHASE 3** | In order to test their predictions, students pose questions, suggest design of experiments and actions, set-up and/or run an experiment, observe the evolution of the phenomena. Students may change the values of the parameters and/or make new predictions on the basis of their findings, and run again the experiment. |
| **PHASE 4** | Students compare their initial views/predictions with the experimental results take into account discussions in the classroom draw conclusions, relate experimental results with the everyday situation and compare them with their initial views<br>**For example from the same Worksheet 6:**<br><br>***Conclusion***<br>- *Which is the physical quantity that is different in the two experimental settings (cooling down the water in a vessel with thick or thin wall)?*<br>- *Does the time needed to cool down a quantity of water depend on the thickness of the wall of the vessel containing it? If it does, can you describe this relation?*<br>- *Can you express a law?*<br>***When the thickness of a material*** *………………………..,*<br><br>***then the heat flow (conduction)*** *…………………………….*<br>- *Discuss with your teacher some examples from your every-day life.*<br>- *Was your prediction right?*<br>- *Were there differences between the actions you planned at chapter: "2. Study of the problem" and the activities you followed at the virtual laboratory? .................* |

### III.2. ENHANCING THE DESIGN OF EXPERIMENTAL INVESTIGATIONS

The ability to design experimental investigations, i.e. to address a problem, by adequately planning an experiment, the results of which will lead to its solution, is considered to be one of the most important of those skills linked to laboratory investigations (Johnstone & Al-Shuaili, 2001). Various schemes have been proposed for the gradual shifting of the responsibility for the various tasks gradually from teacher to student. We have used and adapted such a frame, in the case of our students who are used to traditional teaching rather than to investigative activities. Du et. al. (2005) have proposed a scheme to model the experimental design (i.e. the "ability to design and conduct experiments") in an inquiry-based learning. In their modelling, they have classified in-class experiments from "demonstration and cookbook lab" to "student-directed and student-designed inquiry".

In our case we have adopted several levels from demonstration experiment to student-directed inquiry. Along the module students are gradually introduced to aspects of inquiry through activities in their worksheets. Students are practicing observation, and this is done through a demo experiment in WS3. Students are guided to their observation in their WS. The aims of WS4 are twofold: to facilitate students to reach own conclusion based on evidence and to help students plan an experimental procedure to solve a problem. In WS5 students are asked to design and test an experimental procedure to solve a problem. Finally, in WS6 students are asked to identify a problem, formulate questions and design and carry out experiments to solve it. In summary there is the following sequence:

- **Demo Lab:** Teacher performs an experiment; students watch (in WS 3).
- **Structured Lab:** Teacher sets a procedure; students reach own conclusion based on evidence (in WS4).
- **Pre-challenge Lab:** Teacher poses the problem; students plan solutions (in WS4).
- **Challenge Lab:** Teacher poses a problem; students design and test solutions (in WS5).
- **Student-directed inquiry:** Teacher selects topic; students identify problems, pose questions and design experiments (in WS6).

### III.3. EXPLORATIVE USE OF MODELS

In some Units, like Unit2 and Unit3, microscopic models are presented by teachers and students are guided to observe the models and what it represents and then the model is explored by the students in interpreting phenomena. In other words microscopic models are given to students who will then explore them in order to interpret phenomena. We consider that this is an important aspect of investigative activities. Students work in groups, solve problems, explore models and are engaged in classroom discussion on the problem at study.

Affordances for prompting and guided observation and exploration of these models are provided by the combined effect of worksheets and software that allow students to visualize processes running over time. For example, the following extract is from WS 2:

***Observing the model***

*Figure 1 shows how do scientists think that the lattice of a ceramic material is. This image represents the lattice of the material, which in fact is much smaller and more complex. This is a model of the lattice of ceramics,*

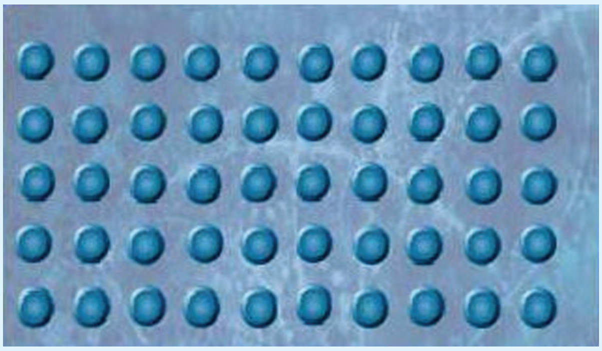


FIG. 1

*How are the particles depicted in Fig. 1? ...........*
*How is the structure of the particles across the lattice? .....................................*

***A4. Observation and exploration of the model in the simulation***

*Now run the simulation titled "Microscopic Model" and then run "Lab1".*

- *Press "Step A1" to start. You will see how do the particles in a ceramic material oscillate at a low temperature. By the term "oscillation" we mean the continuous motion of particles around a fixed position.*

***Watch the simulation on the screen and discuss with your group the following:***

- *Can you observe the oscillation of the particles on the screen?*

  *YES* ☐ *NO* ☐
- *Could you observe this oscillation of the particles on the image of Fig. 1?*

  *YES* ☐ *NO* ☐
- *Use the right arrow to proceed to the next animation, where you can observe the oscillation of the particles at moderate and high temperatures. Which differences do you observe in their oscillation, now that the temperature of the material is higher? ………………*
- *Use the right arrow to proceed to the last animation, where you can vary the temperature at will and observe the corresponding oscillation of the particles. Try to lower the temperature as much as you are allowed to. What to you observe?........*

***5. Conclusion***

- *How is the oscillation of the particles affected by the increase or the decrease of the temperature?..................*
- *What happens to the kinetic energy of the particles as long as the temperature increases?...................*

## IV. METACOGNITION AND METACONCEPTUAL AWARENESS

We should mention that in science education, metacognition and, more specifically, metaconceptual awareness is considered as a facilitating condition for changing of the existing cognitive structures into new more scientifically plausible ones. Prompting students to reflection over their inquiry activities during laboratory work would help students to get feedback for their actions, thoughts, and learning procedures. Reflection is the process in which a person re-thinking over his/her cognitive activity, for example, during case experimental inquiry. During reflection students become more aware of the facts and the demands of the inquiry process, of their explanatory conceptions and develop metacognitive skills such as monitoring, revision, and evaluation.

In the TLS care is taken to facilitate students' reflective thinking on the performed tasks. Students are encouraged to do science while thinking about science so that they do not formulate an idea that inquiry is only procedural.

For example in Unit 4.:

5.1 *What steps did you follow to find out which rod was the most conductive?*

5.2 *Were there some differences between what you finally did and your initial design? If YES, which were the differences?*

Furthermore, asking questions that promote metacognitive awareness for the inquiry activity, would lead students to think about why they are conducting certain processes and evaluate their thinking in terms of the way a scientist might think about the processes and outcomes. Another example is that in the last two Units students are guided by the teacher to reflect on their previous taught knowledge and procedures they followed

In the case of models it is well known that they primarily used for illustrative or communicative purposes, thus limiting the epistemic richness of the scientific inquiry (Windschitl, Thompson, & Braaten, 2008). Teachers have limited experience with scientific modeling, lack knowledge about students' ideas (Justi & Gilbert, 2002) and often see models as useful for teaching about science content, but not about the nature of science (Henze, Van Driel, & Verloop, 2007).

We attempt to promote evolution of student's ideas and understanding of the nature and purpose of models, and of their effective use in scientific inquiry. This knowledge about models and modeling is a type of nature of science understanding (Lederman, 2007) that we refer to as metamodeling knowledge (Schwarz & White, 2005). Learners need to understand how models are used, why they are used, and what their strengths and limitations are, in order to appreciate how science works and the dynamic nature of knowledge that science produces (Abd-El-Khalick et al., 2004). We consider that metamodeling knowledge guides the inquiry process by helping students engage in the practice, enabling to more effectively plan and evaluate their investigations. Knowing the nature and purposes of scientific models and criteria for use them can help guide learners in more successful and reflective use of models in scientific reasoning (Schwartz, 2002; Schwarz et al., 2009).

For example in From Unit 3:

6.4. *Answer the following questions:*
   i. *What did you achieve by using models in the lesson?......*
   ii. *What do you think that a model finally is? What does it represent?....*

## V. USE OF EVERYDAY LIFE APPLICATIONS AND AN INTEGRATIVE SCENARIO

Finally, several tasks throughout the module are embedded in everyday life situations in order to motivate students. Besides they are asked to classify materials according to their thermal conductivity and to relate them to everyday use. We assume that students will be motivated not only by technological applications but from the enriched learning environment as well as by their active participation in the investigative activities. Finally, students are gradually guided to think and wonder about the energy saving house and how they can apply their taught knowledge in order to decrease heat losses.

For example from Unit 8

2.1. *You may now suggest some ways to reduce heat losses from the house to the environment and therefore save energy.*

# 7. RELEVANT ICT TOOLS

## 7.1. THE WEB-BASED ENVIRONMENT

The web-based environment, shown in Fig. 7.1, is the place to hold the materials produced in the Material Science project.

The introductory screen is divided into two parts, the left-most part, where the menu of accessing the material is presented and the right part, where an interactive picture is located. The menu is

- **Instructions:** where instructions for the use of the module, and system requirements can be found.
- **Real Experiments:** where can be found a collection of videos for the real experiments used in the module.
- **Simulated Experiments:** where the simulated experiments used in the module can be found.
- **Microscopic Models:** where the microscopic models used in the module can be found.
- **The Greek Module:** where one can find the Greek implementation of the module.
- **About:** where information about the module, and the designing team can be found.

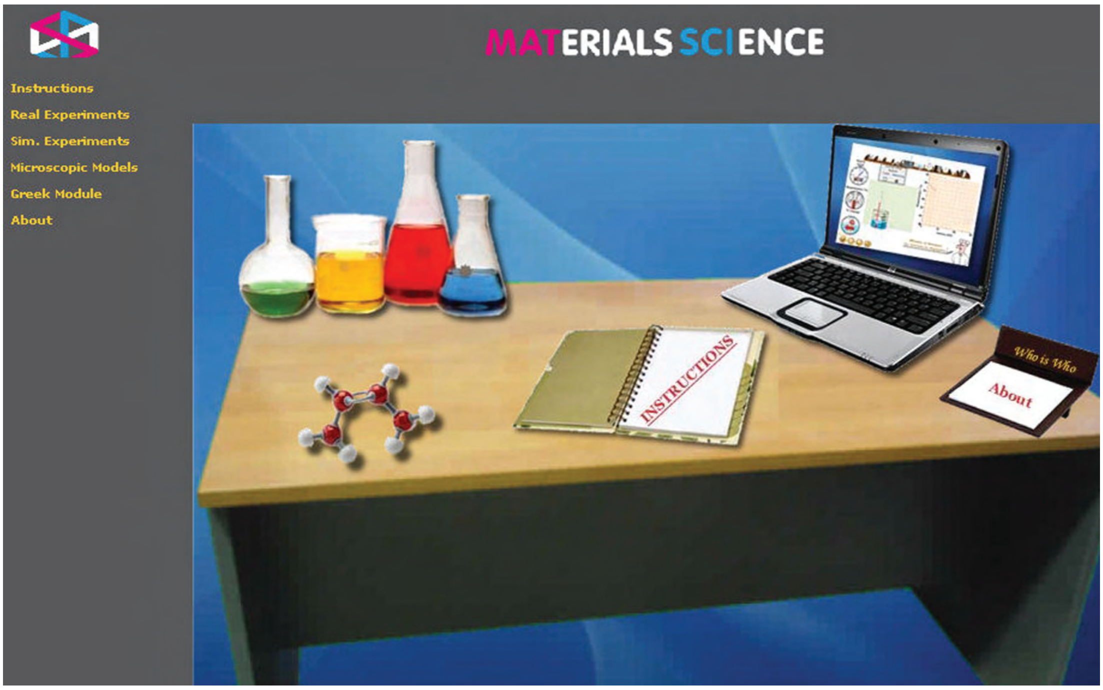



FIGURE 7.1: THE INTRODUCTORY SCREEN OF THE WEB-BASED ENVIRONMENT

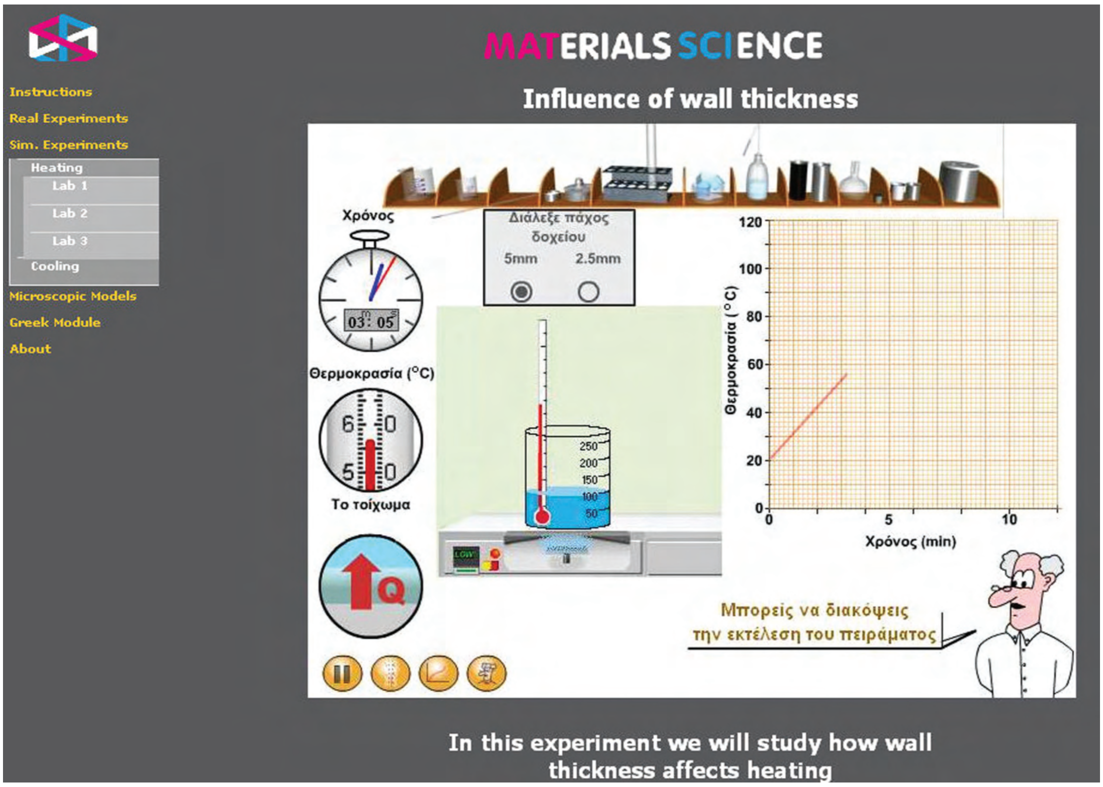



FIGURE 7.2: TYPICAL SCREEN-SHOT FOR THE SIMULATED EXPERIMENTS

Menu, is organized in sub-menus which include:

- Intro: where introductory remarks can be found.
- Theory: where the relevant theoretical background information can be found.
- Lab (or Steps): where either the lab (on simulated experiments) or the steps (in microscopic models) can be found.
- Worksheet: where the students' worksheet can be found.
- Teacher Tips: where tips and hints for the teacher can be found.

A typical unfolded structure of the sub-menus in simulated experiments is shown in Fig. 7.2. Bellow, are presented in brief the "Real Experiments", the "Simulated Experiments" and the "Microscopic Models"

## 7.2. HANDS ON (REAL) EXPERIMENTS

Three (3) hands on real experiments have been developed. The experiments deal with thermal equilibrium, thermal conductance of different materials and thermal conductance of different metals and alloys.

### Experiment 1: Thermal equilibrium

**Scope:** the scope of the experiment is:

- to study the thermal interaction between two equal amounts of water of different initial temperature
- to study the final temperature after the thermal interaction

### Components

- two glass beakers one 400ml and another 150ml
- two laboratory thermometers
- a timer/stopwatch

FIGURE 7.3: EXPERIMENT 1

**Description of the experiment**
The experimental setup is composed as shown in Figure 7.3: The two beakers are placed one into the other. The inner beaker contains hot water, while the outer one cold (tab) water. Two thermometers are placed one in each beaker. The students are asked to write down the time evolution of the temperatures

### Experiment 2: Thermal conductance of different materials

**Scope:** the scope of the experiment is:

- to study the rate of heat transfer in different materials
- to study the time required to reach the final temperature in a thermal equilibrium experiment regarding the material used.

**Components**

- one large vessel
- one glass beaker, one ceramic and one plastic, 100ml each
- two laboratory thermometers
- a timer/stopwatch

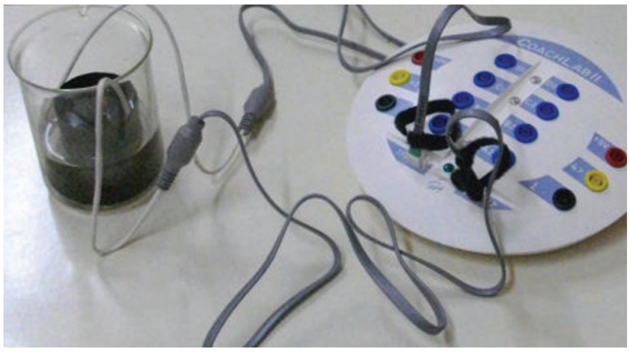


FIGURE 7.4: EXPERIMENT 2

**Description of the experiment**
The experimental setup is composed as shown in Figure 7.4: The small beaker (glass, ceramic plastic) is placed one inside the lager vessel. The inner beaker contains hot water, while the large vessel cold (tab) water. Two thermometers are placed one in each beaker. The students work in groups and are asked to write down the time evolution of the temperatures. The teacher summarized the time reported by each group, with respect to the material of the beaker.

### Experiment 3: Thermal conductance of different metals and alloys

**Scope:** the scope of the experiment is:

- to study (and to rank) the different metals and alloys with respect to their thermal conductivity

**Components**

- a set of 5 metal bars of equal length and cross-section
- a set of 5 small candles
- thermographic (fax) paper
- a timer/stopwatch

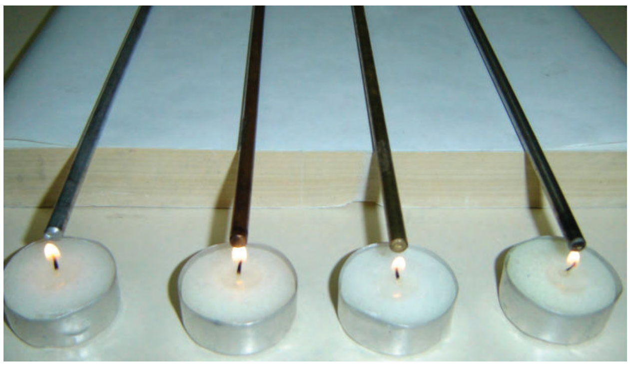


FIGURE 7.5: EXPERIMENT 3

**Description of the experiment**

The experimental setup is composed by placing the set of the 5 metal bars on a book and the 5 small candles aligned in a row well far from the edges of the metal bars. The thermographic (fax) paper is placed under the bars. Students are asked to lit-up the candles first and then push then by a ruler so that the flame heats the edge of each metal bar (as shown in Figure 7.5). After about 10 min, the students are asked to blow out the candles and observe the mark (the trace) on the fax paper.

## 7.3. SIMULATED EXPERIMENTS

Seven (7) experiments have been developed as flash simulations. The simulated experiments are:

| | |
|---|---|
| **SIMLAB 1** | The role of the material's thickness in heat transfer, compare between 2.5 and 5mm thickness (Flash simulation) |
| **SIMLAB 2** | The role of the material's thickness in heat transfer, compare between 2.5 and 7mm thickness (Flash simulation) |
| **SIMLAB 3** | The role of the material's area in heat transfer, in cooling (Flash simulation) |
| **SIMLAB 4** | The role of the material's area in heat transfer, in heating (Flash simulation) |
| **SIMLAB 5** | The role of material in heat transfer, compare between glass and plexiglass (Flash simulation) |
| **SIMLAB 6** | The role of material in heat transfer, compare between glass and vacelite (Flash simulation) |
| **SIMLAB 7** | The role of material in heat transfer, compare between glass and rubber (Flash simulation) |

**SimLab 1:** The role of the material's thickness in heat transfer, compare between 2.5 and 5mm thickness

**Scope:** the scope of the experiment is:

- to investigate the role of material's thickness in heat transfer

**Description of the experiment**

The Flash simulation (shown in Figure 7.6) consists of two beakers one inside the other. The experiment is setup up by clicking on the small beaker and on the thermometer, according to the virtual teacher's instructions. The small beaker contains 50ml of water at 80°C while the larger one 50ml of water at 20°C. The time, temperature, and a zoom in the beaker's wall are shown in the three circles on the left-most side of the simulation. A red arrow indicates the rate of the heat transfer from the inner beaker to the outer, dimming upon the value of heat transfer. With this experiment students are asked to observe the time evolution of the temperature if the inner beaker has 2.5mm or 5mm thickness.

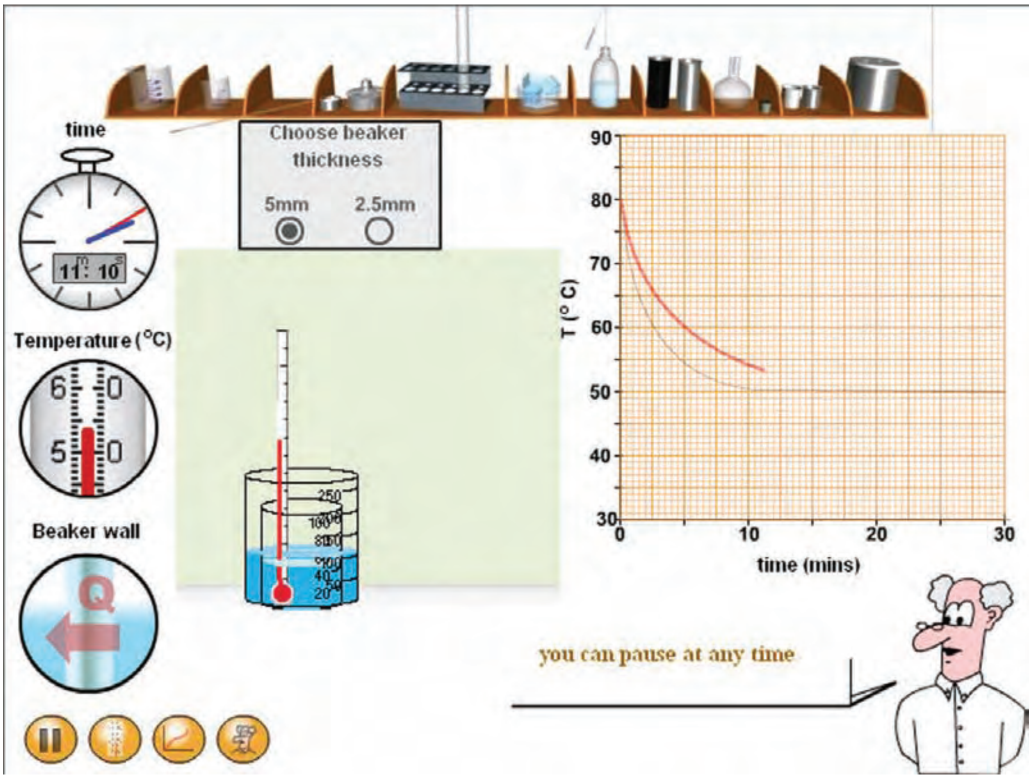



FIGURE 7.6: EXPERIMENTAL SETUP AND RESULTS FOR SIMLAB 1

**SimLab 2:** The role of the material's thickness in heat transfer, compare between 5 and 7.5mm thickness

**Scope:** the scope of the experiment is:

- to investigate the role of material's thickness in heat transfer

**Description of the experiment**

The Flash simulation (shown in Figure 7.7) consists of two beakers one inside the other. The experiment is setup up by clicking on the small beaker and on the thermometer, according to the virtual teacher's instructions. The small beaker contains 50ml of water at 80°C while the larger one 50ml of water at 20°C. The time, temperature, and a zoom in the beaker's wall are shown in the three circles on the left-most side of the simulation. A red arrow indicates the rate of the heat transfer from the inner beaker to the outer, which is dimmed upon the value of heat transfer. With this experiment students are asked to observe the time evolution of the temperature if the inner beaker has 5mm or 7.5mm thickness.

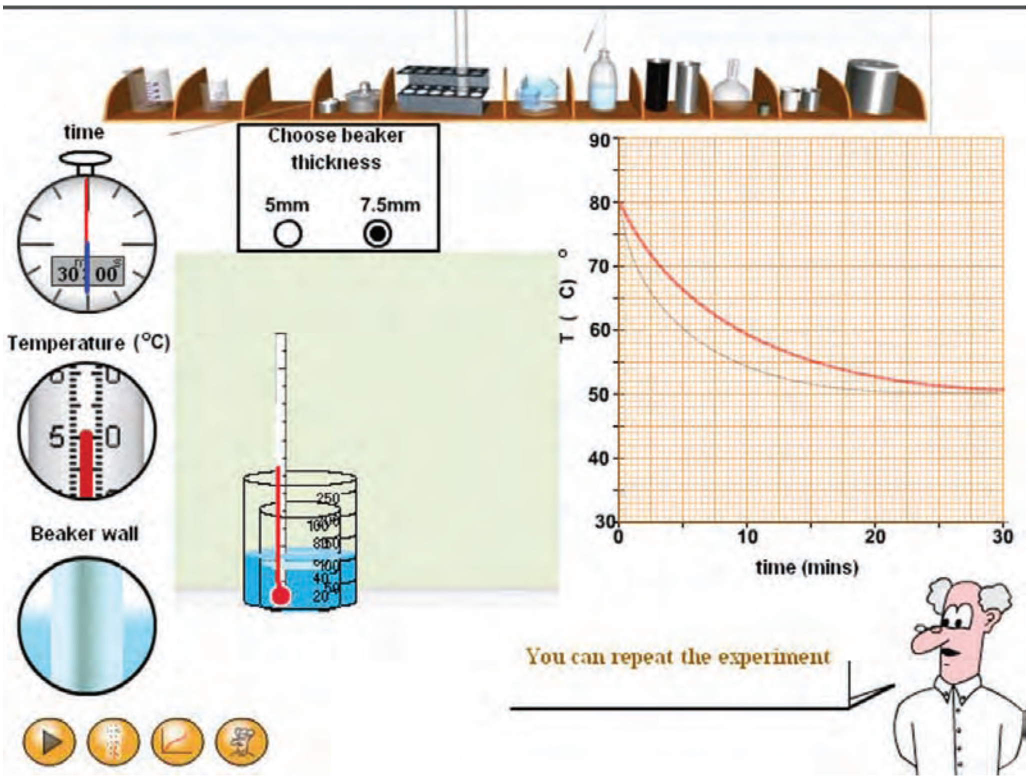



FIGURE 7.7: EXPERIMENTAL SETUP AND RESULTS FOR SIMLAB 2

**SimLab 3:** The role of the material's area in heat transfer, in cooling

**Scope:** the scope of the experiment is:

- to investigate the role of material's area in heat transfer

**Description of the experiment**

The experiment (shown in Figure 7.8) consists of two conical flasks one with large surface area and another with a smaller one, and a large vessel. The experiment is setup up by clicking on the conical flask and on the thermometer, according to the virtual teacher's instructions. The time and temperature are shown in the two circles on the left-most side of the simulation. With this experiment students are asked to observe the time evolution of the temperature if we replace the lager conical flash with a smaller one.

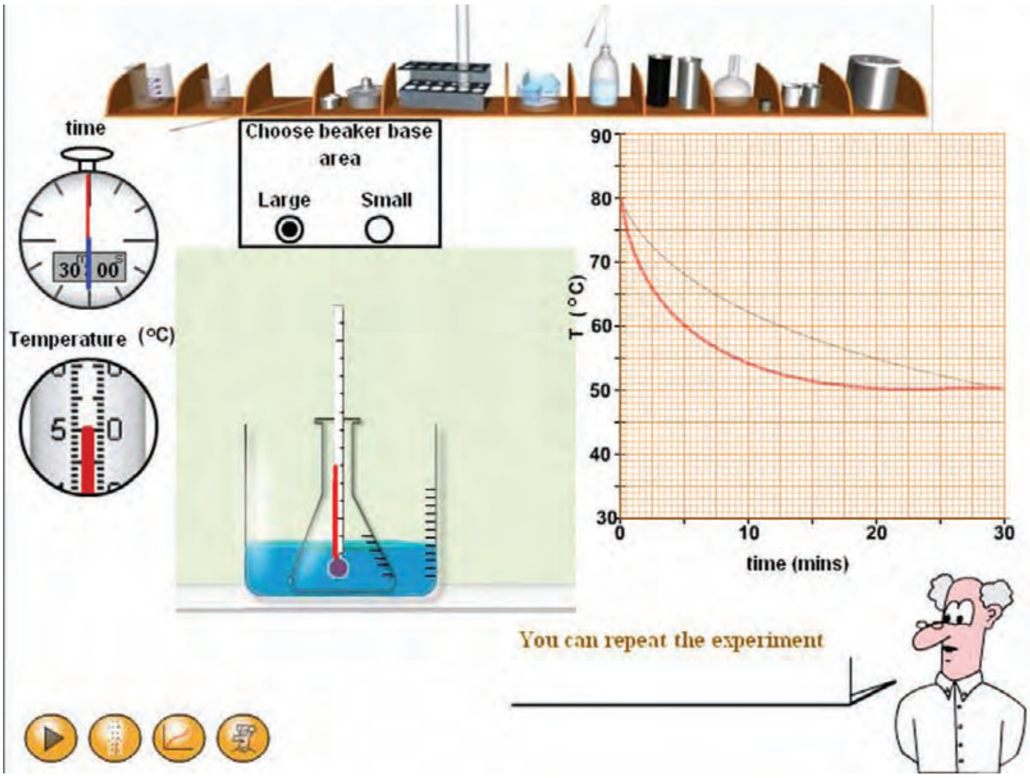



FIGURE 7.8: EXPERIMENTAL SETUP AND RESULTS FOR SIMLAB 3

**SimLab 4:** The role of the material's area in heat transfer, in heating

**Scope:** the scope of the experiment is:

- to investigate the role of material's area in heat transfer

**Description of the experiment**

The experiment (shown in Figure 7.9) consists of two conical flasks one with large surface area and another with a smaller one both heated up with the same rate. The experiment is setup up by clicking on the thermometer, according to the virtual teacher's instructions. The time and temperature are shown in the two circles on the left-most side of the simulation. With this experiment students are asked to observe the time evolution of the temperature if we replace the lager conical flash with a smaller one.

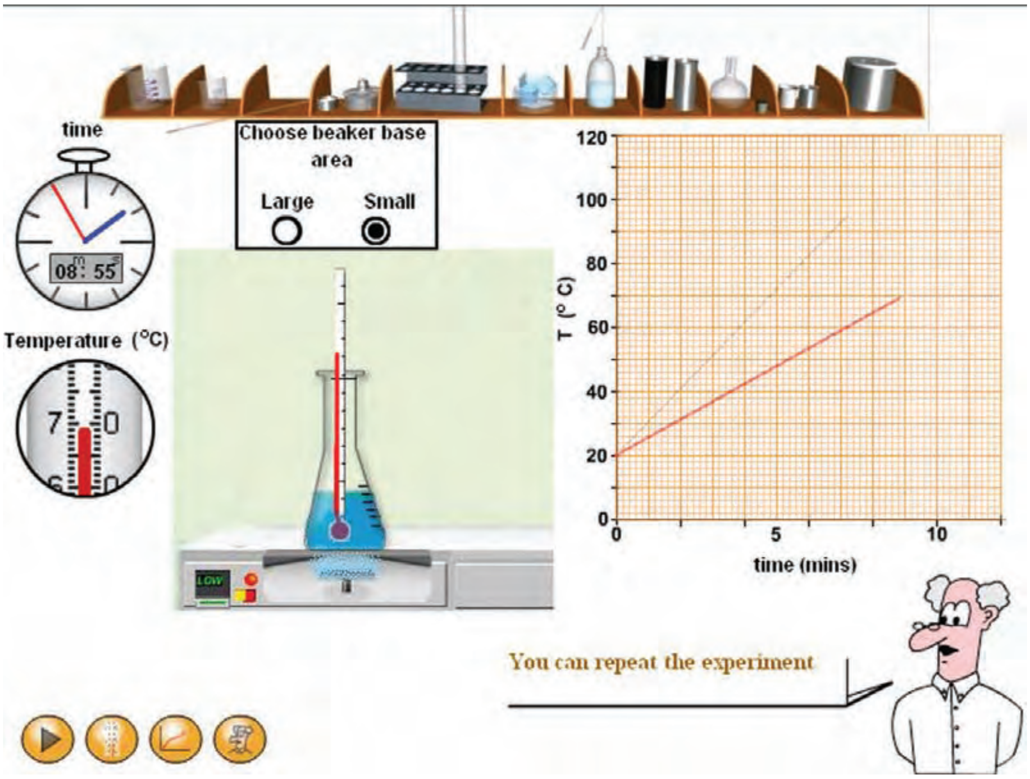



FIGURE 7.9: EXPERIMENTAL SETUP AND RESULTS FOR SIMLAB 4

**SimLab 5:** The role of material in heat transfer, compare between glass and plexiglass

**Scope:** the scope of the experiment is:

- to investigate the role of material in heat transfer

**Description of the experiment**

The Flash simulation (shown in Figure 7.10) consists of two beakers one inside the other. The experiment is setup up by clicking on the small beaker and on the thermometer, according to the virtual teacher's instructions. The small beaker contains 50ml of water at 80°C while the larger one 50ml of water at 20°C. The time, temperature, and a zoom in the beaker's wall are shown in the three circles on the left-most side of the simulation. A red arrow indicates the rate of the heat transfer from the inner beaker to the outer, which is dimmed upon the value of heat transfer. With this experiment students are asked to observe the time evolution of the temperature if the inner beaker is made of glass or plexiglass.

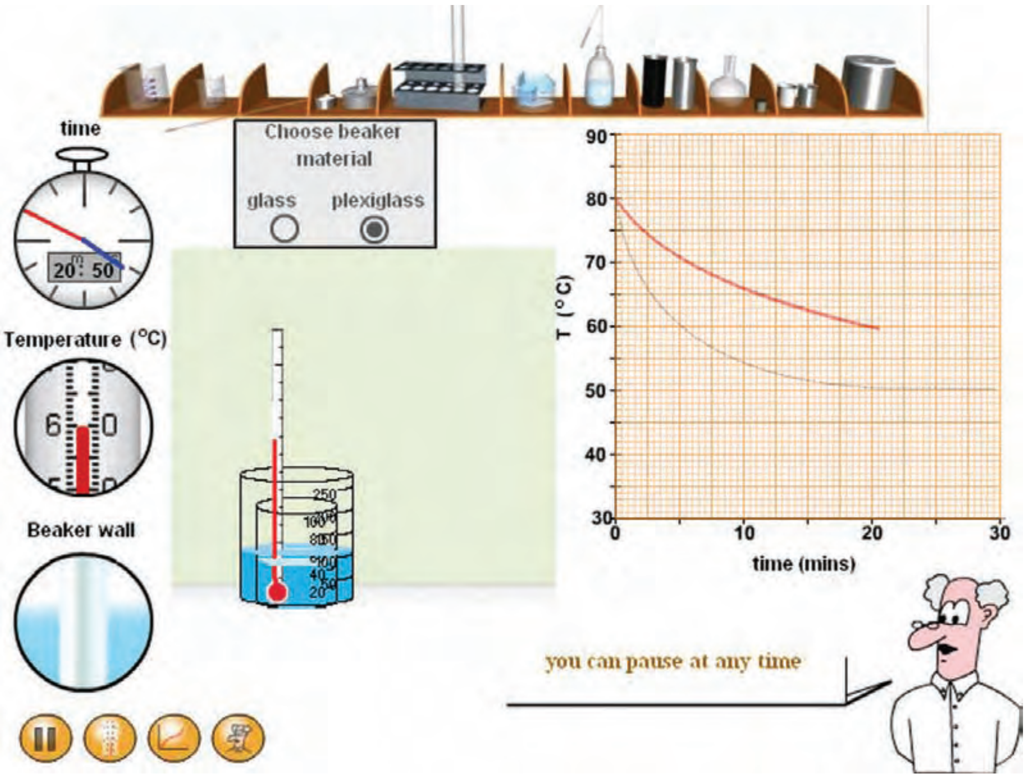



FIGURE 7.10: EXPERIMENTAL SETUP AND RESULTS FOR SIMLAB 5

**SimLab 6:** The role of material in heat transfer, compare between glass and Bakelite

**Scope:** the scope of the experiment is:

- to investigate the role of material in heat transfer

**Description of the experiment**

The Flash simulation (shown in Figure 7.11) consists of two beakers one inside the other. The experiment is setup up by clicking on the small beaker and on the thermometer, according to the virtual teacher's instructions. The small beaker contains 50ml of water at 80°C while the larger one 50ml of water at 20°C. The time, temperature, and a zoom in the inner beaker's wall are shown in the three circles on the left-most side of the simulation. A red arrow indicates the rate of the heat transfer from the inner beaker to the outer, which is dimmed upon the value of heat transfer. With this experiment students are asked to observe the time evolution of the temperature if the inner beaker is made of glass or bakelite.

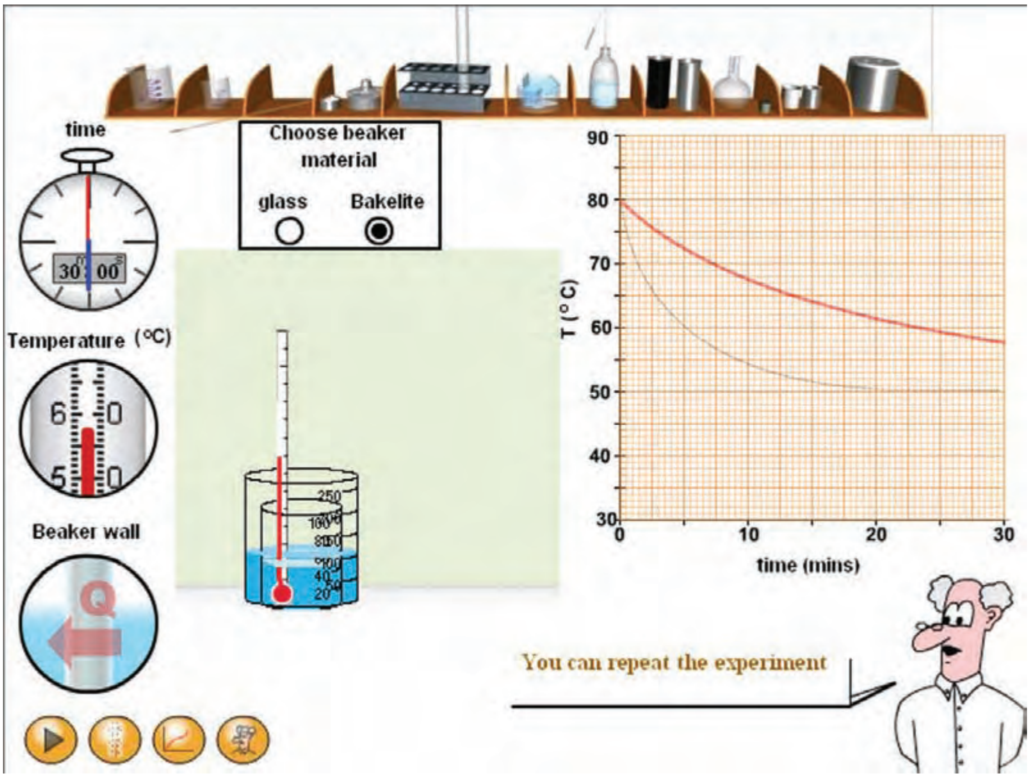



FIGURE 7.11: EXPERIMENTAL SETUP AND RESULTS FOR SIMLAB 6

**SimLab 7:** The role of material in heat transfer, compare between glass and rubber

**Scope:** the scope of the experiment is:

- to investigate the role of material in heat transfer

**Description of the experiment**

The Flash simulation (shown in Figure 7.12) consists of two beakers one inside the other. The experiment is setup up by clicking on the small beaker and on the thermometer, according to the virtual teacher's instructions. The small beaker contains 50ml of water at 80°C while the larger one 50ml of water at 20°C. The time, temperature, and a zoom in the inner beaker's wall are shown in the three circles on the left-most side of the simulation. A red arrow indicates the rate of the heat transfer from the inner beaker to the outer, which is dimmed upon the value of heat transfer. With this experiment students are asked to observe the time evolution of the temperature if the inner beaker is made of glass or rubber.

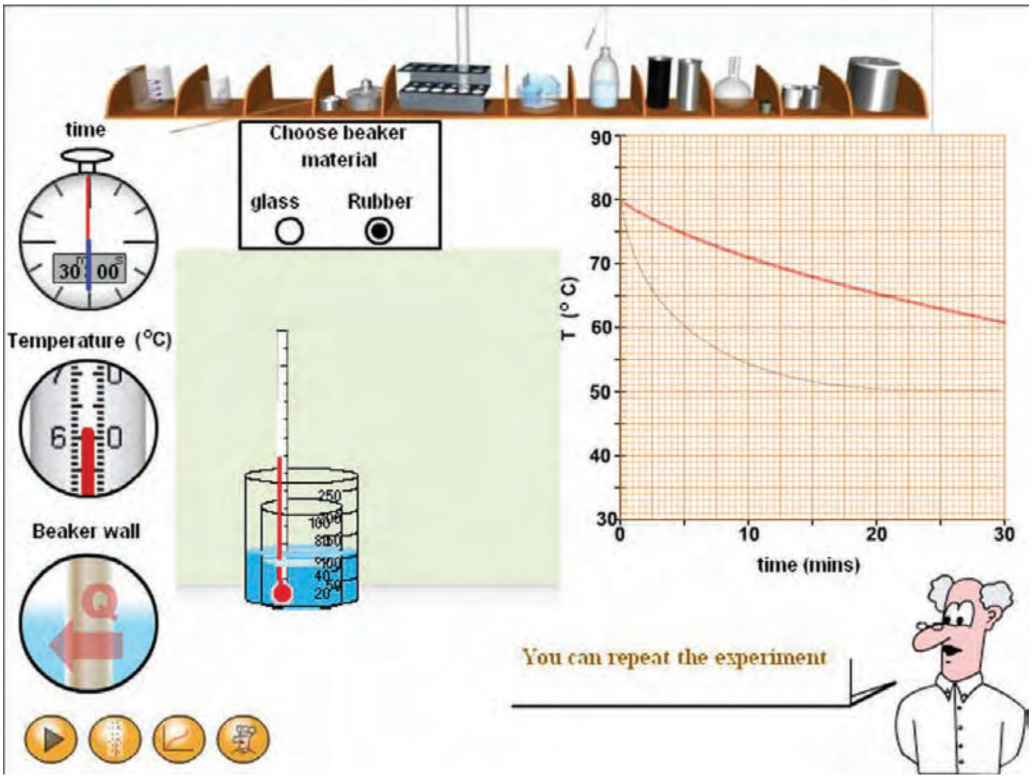



FIGURE 7.12: EXPERIMENTAL SETUP AND RESULTS FOR SIMLAB 7

## 7.4. MICROSCOPIC MODELS

### 7.4.1. COMMENTS ON MICROSCOPIC SIMULATIONS

In our microscopic simulations, we consider the heat conduction in a transient state. As can be seen in Fig. 7.13, the rod is heated up, in one end, and we observe the evaluation on the temperature gradient profile during the heating process. The microscopic simulations actually indicate the transient process: the columns of atoms are gradually changing the amplitude of their oscillatory motion as heat propagates through the solid. This change in amplitude of oscillatory motion is due to the transient heat transfer.

The problem of heating up a rod of material at one end of it is a rather complex one, as it involves:

(a) Heating up of the point where heat is applied. The rate of the change in the temperature is related to the **specific heat** of the material

(b) The heat propagated through the material at a rate which is proportional to the **thermal conductivity** of the material

(c) The cold parts of the rod are heated up, and this is related to the **specific heat** of the material

(d) The hotter parts of the material radiate heat to the surrounding environment.

Speaking strictly scientifically, in a transient case one should use the concept of thermal diffusivity. In school textbooks the term "**thermal diffusivity**" is not introduced, while is used the term "thermal conductivity". The conduction of heat, in school textbooks is treated on a qualitative basis: fast-conducting materials (good thermal conductor) as opposite to slow-conducting materials (thermal insulator). Therefore, we have adopted the didactical transformation thermal diffusivity → thermal conductance → thermal conductivity. Scientifically, results do not differ qualitatively, since the coefficient of thermal diffusivity is proportional to the coefficient of thermal conductivity.

A typical screen-shot of a microscopic model is presented in Figure 7.14. The simulation screen is divided in 4 parts. The middle part shows a bar being heated. The heating of the bar is depicted by the

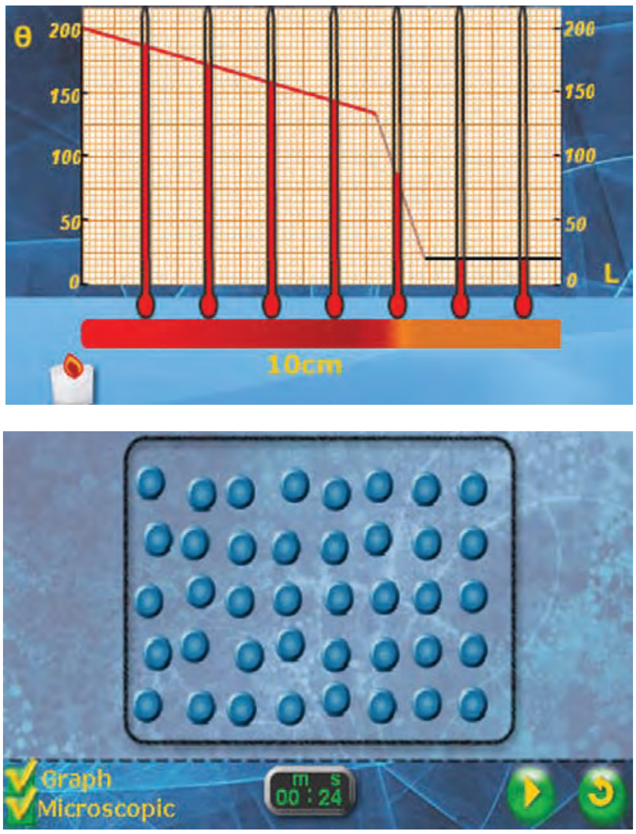



FIGURE 7.13: SIMULATION OF HEAT TRANSFER

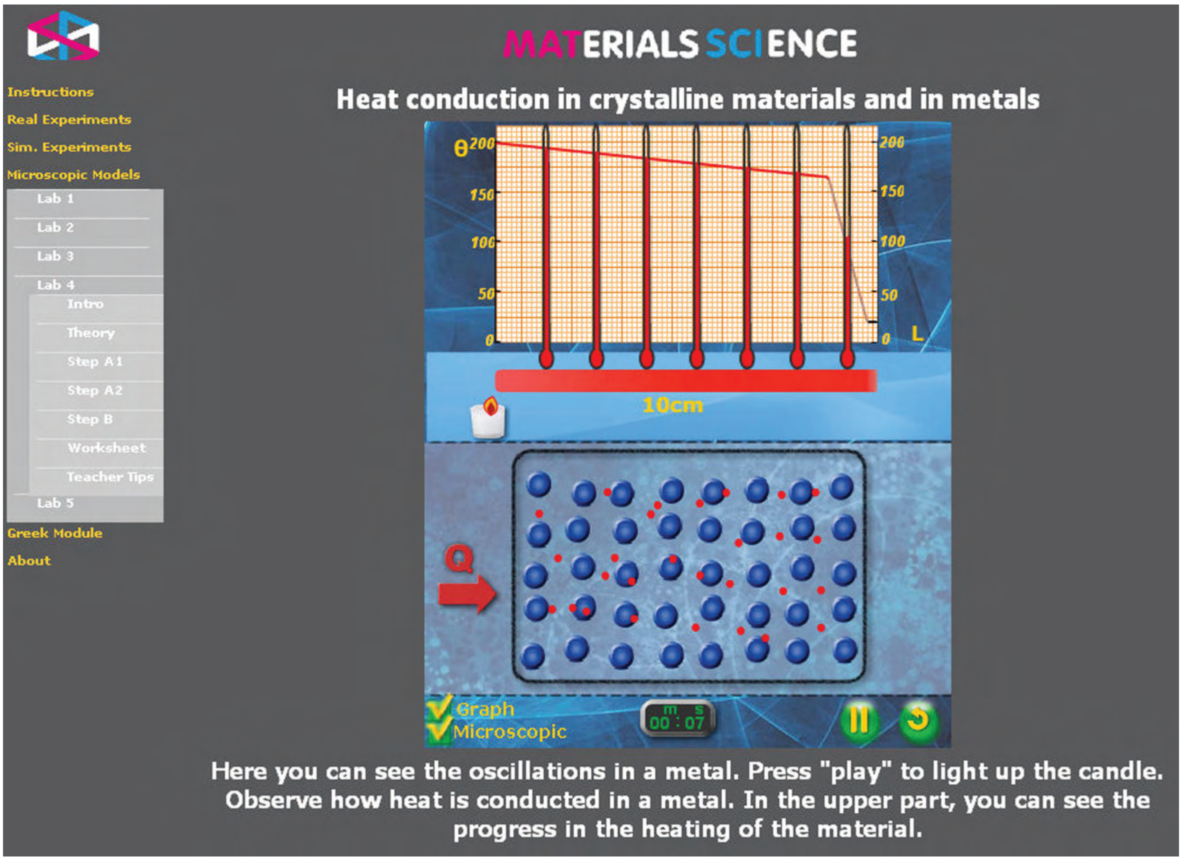



FIGURE 7.14: TYPICAL SCREEN SHOT FOR THE MICROSCOPIC SIMULATIONS

change in color, from bright red to darker-red. The color gradient is used to indicate the temperature gradient within the material while the bar is heated. A set of thermometers, in the upper part, and the corresponding graph, indicate the change in the temperature along the bar. The microscopic model is depicted in the middle-lower part. The atoms are arranged in a grid to simulate the lattice. Smaller red dots represent the electrons. The lowest part is the place for the controls; "graph" and "microscopic" which toggle the graph and microscopic model on/off, as well as timer and the "pause" and "run" in the right most part.

On the left-most part in Fig. 7.14 one can see the unfolded menu for the microscopic simulations. In Step A1 in the microscopic models, is represented the case of heat transfer in crystalline ceramics, while in Step A2, is represented the corresponding theme (amorphous, density, metals, etc.). In Step B, the two simulations are presented together for direct comparison.

### 7.4.2. DESCRIPTIONS OF THE SIMULATIONS

Six (6) simulations were developed to address the microscopic models for the heat transfer in materials.

The microscopic simulations (developed in Flash) are:

- **SimMicro 1:** The microscopic model of Heat and Temperature
- **SimMicro 2:** The microscopic model of Heat Transfer in crystalline and amorphous solids
- **SimMicro 3:** The effect of density in the heat transfer.
- **SimMicro 4:** The role of electrons in heat transfer
- **SimMicro 5:** Comparison for metals and alloys

**SimMicro 1:** The microscopic model of Heat and Temperature

**Scope:** the scope of the simulation is:

- to familiarize the students with the microscopic model of a solid
- to investigate the effect of temperature and heat in microscopic description

**Description of the simulation**

The Flash simulation (shown in Figure 7.15) consists of a set of rigid balls arranged in a matrix form to simulate the lattice. The balls are vibrating with small or larger amplitude according to the temperature. Students are asked to observe the vibrational motion of the balls as the temperature rises. In the final part on this simulation, students can freely set the temperature (by clicking on the thermometer) and observe the changes in the motion.

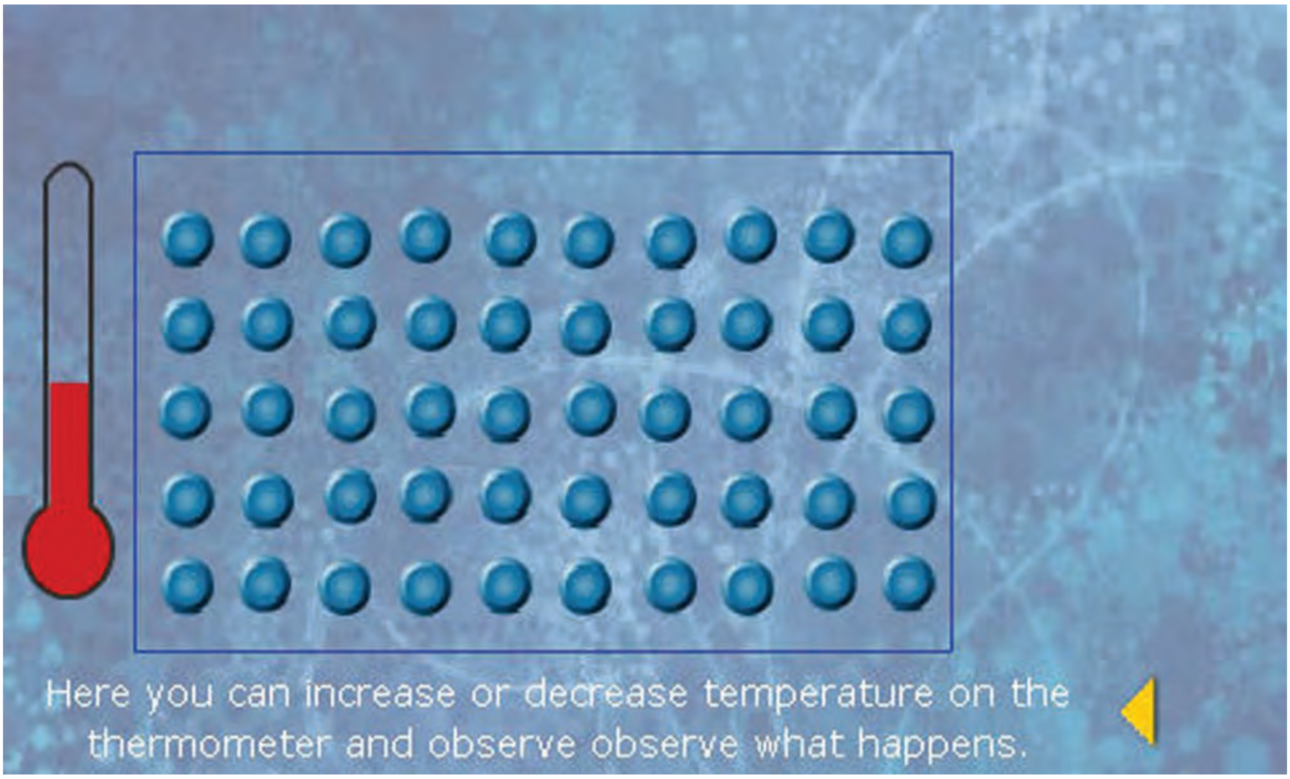



FIGURE 7.15: INTRODUCTION TO THE MICROSCOPIC MODEL ON HEAT AND TEMPERATURE

**SimMicro 2:** The microscopic model of Heat Transfer in crystalline and amorphous solids

**Scope:** the scope of the simulation is:

- to familiarize the students with the microscopic model for heat transfer in a solid
- to investigate the effect structure in a solid (comparison between a crystalline and an amorphous material)

**Description of the simulation**

The Flash simulation (shown in Figure 7.16) consists of a set of rigid balls arranged in a matrix form to simulate the lattice in a crystalline solid. In the right part, the balls are misplaced in position to simulate the amorphous solid. The balls are vibrating with small amplitude at ambient temperature. When the candle is lit up the balls are vibrating at larger amplitude, causing the neighboring balls to vibrate also, and the heat is propagated inside the solid. This propagation of heat is schematically depicted in the white bar on the top. In the first two parts of the simulation, students are asked to observe the vibrational motion, which correspond to the rise of temperature. In the final part on this simulation, students can compare the rate of heat transfer in a crystalline and in an amorphous solid.

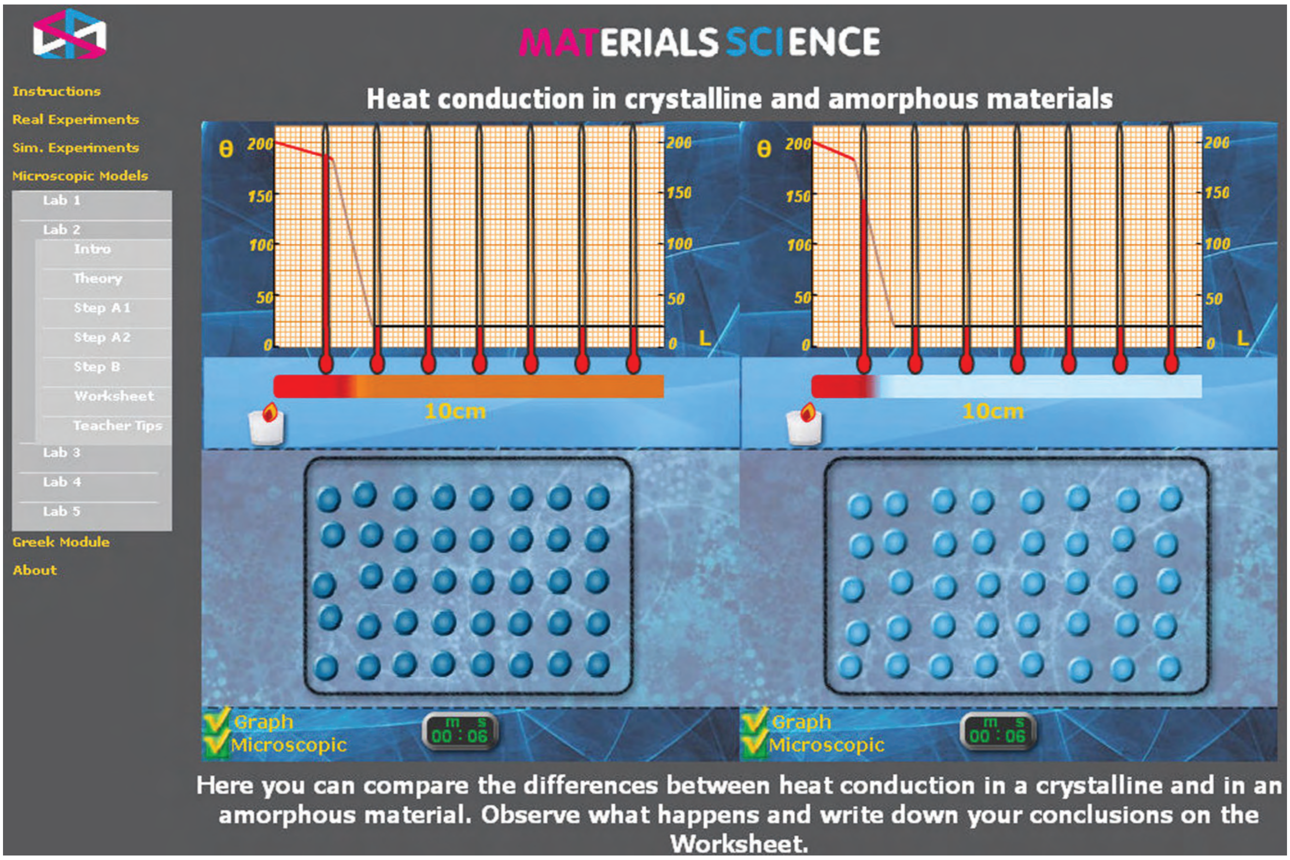



FIGURE 7.16: COMPARISON BETWEEN THE HEAT TRANSFER IN CRYSTALLINE AND AMORPHOUS SOLID.

**SimMicro 3:** The effect of density in the heat transfer.

**Scope:** the scope of the simulation is:

- to work further with the microscopic model for heat transfer in a solid
- to investigate the effect density in a solid

**Description of the simulation**

The Flash simulation (shown in Figure 7.17) consists of a set of rigid balls arranged in a matrix form to simulate the lattice in a crystalline solid. In the right part, the balls are set further apart to simulate a less dense material. The balls are vibrating with small amplitude at ambient temperature. When the candle is lit up the balls are vibrating at larger amplitude, causing the neighboring balls to vibrate also as heat is propagated inside the solid. This propagation of heat is schematically depicted in the white bar on the top. In the first two parts of the simulation, students are asked to observe the vibrational motion, which correspond to the rise of temperature. In the final part on this simulation, students can compare the rate of heat transfer as a function of the density of the material.

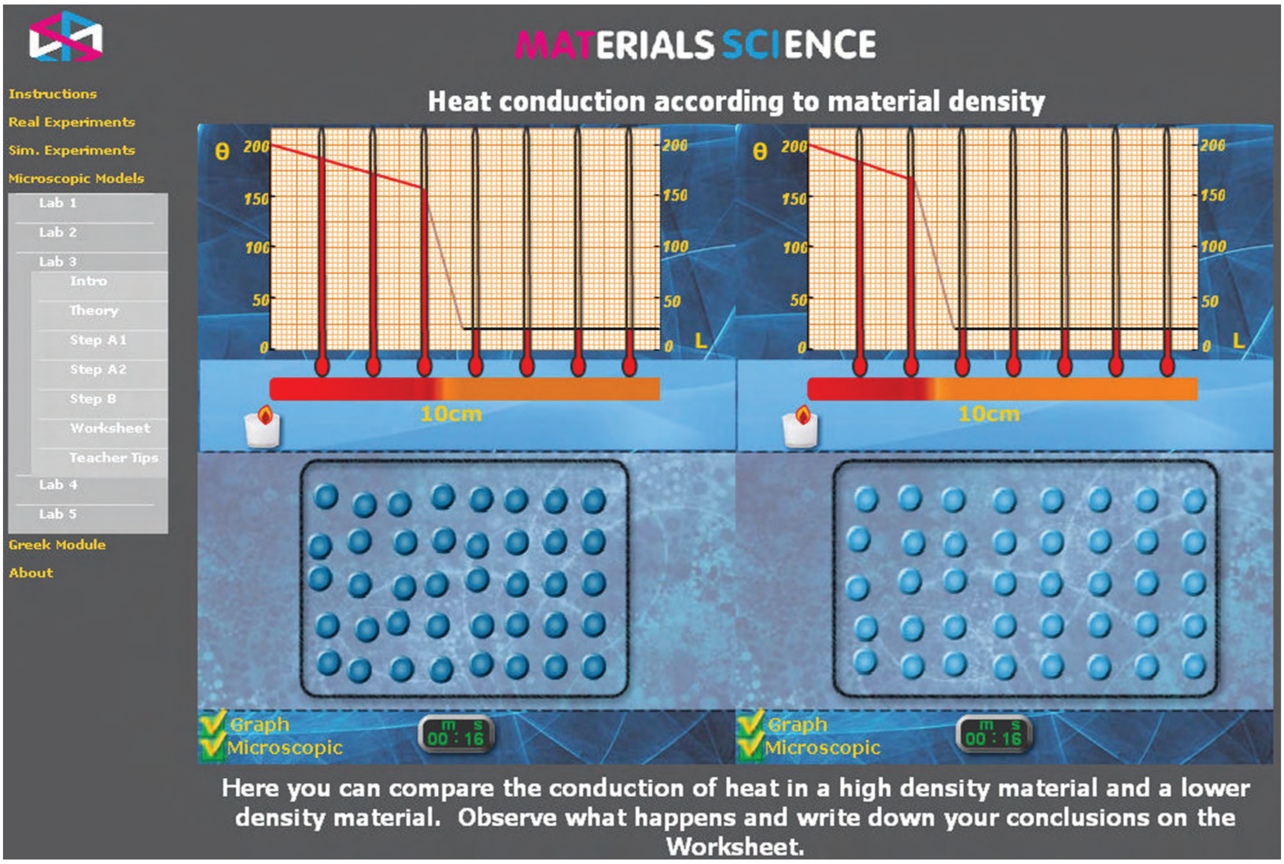



FIGURE 7.17: THE EFFECT OF DENSITY IN THE HEAT TRANSFER

**SimMicro 4:** The role of electrons in heat transfer

**Scope:** the scope of the simulation is:

- to work further with the microscopic model for heat transfer in a solid
- to investigate the effect the electrons in a solid

**Description of the simulation**

The Flash simulation (shown in Figure 7.18) consists of a set of rigid balls arranged in a matrix form to simulate the lattice in a crystalline solid. Second set of small red balls represent the electrons. The balls are vibrating with small amplitude at ambient temperature. When the candle is lit up the balls are vibrating at larger amplitude, causing the neighboring balls to vibrate also as heat is propagated inside the solid. This propagation of heat is schematically depicted in the white bar on the top. In the first two parts of the simulation, students are asked to observe the vibrational motion, which correspond to the rise of temperature. In the final part on this simulation, students can compare the rate of heat transfer as a function of the electrons present in the material.

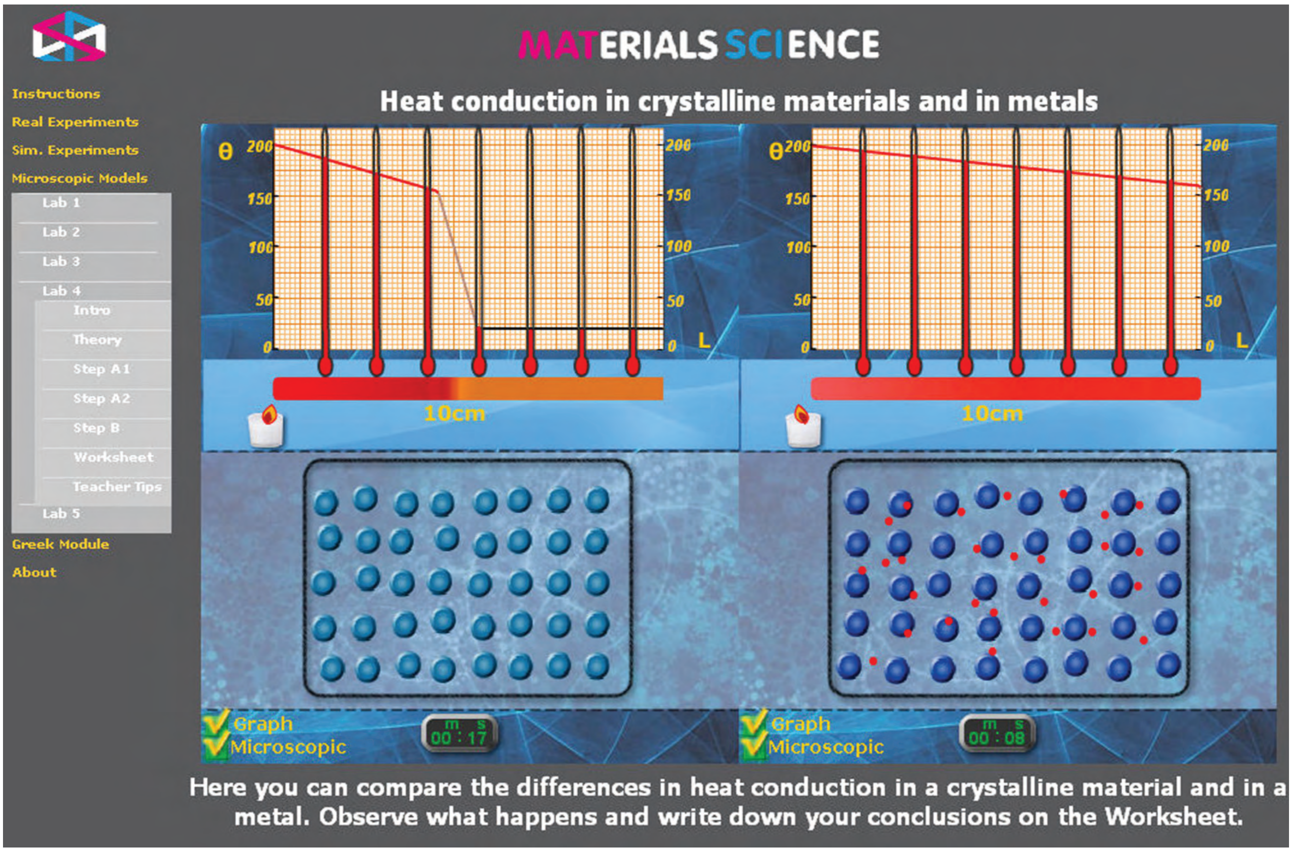



FIGURE 7.18: THE EFFECT OF ELECTRONS IN THE HEAT TRANSFER.

**SimMicro 5:** Comparison for metals and alloys

**Scope:** the scope of the simulation is:

- to investigate the effect the electrons in a solid
- to investigate the effect of alloying

**Description of the simulation**

The Flash simulation (shown in Figure 7.19) consists of a set of rigid balls arranged in a matrix form to simulate the lattice in a crystalline metal. Second set of small red balls represent the electrons. In the right part of Figure 24, is shown an alloy. The balls are vibrating with small amplitude at ambient temperature. When the candle is lit up the balls are vibrating at larger amplitude, causing the neighboring balls to vibrate also as heat is propagated inside the solid. This propagation of heat is schematically depicted in the white bar on the top. In the first two parts of the simulation, students are asked to observe the vibrational motion, which correspond to the rise of temperature. In the final part on this simulation, students can compare the rate of heat transfer in the two solids (a pure metal and a metallic alloy).

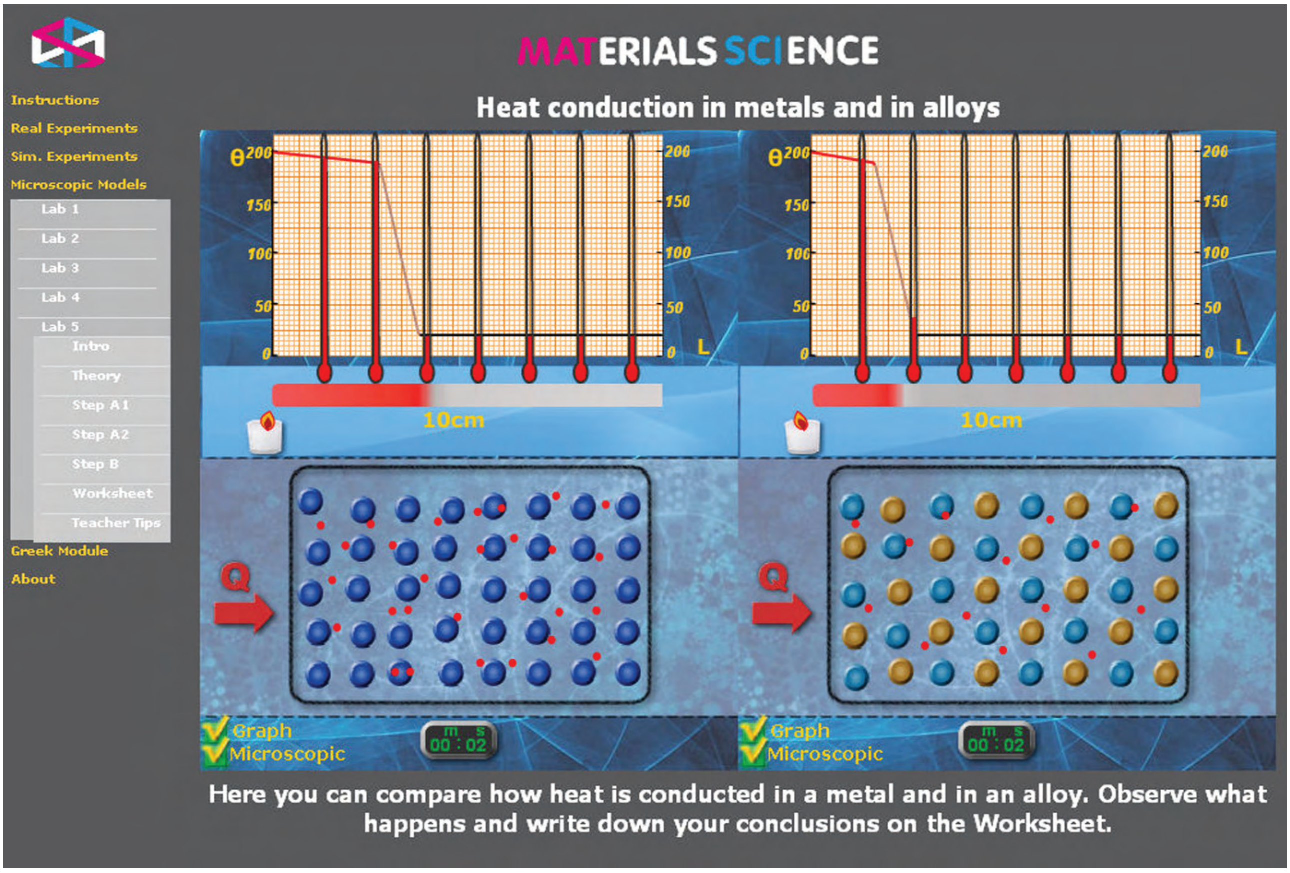



FIGURE 7.19: COMPARISON BETWEEN A METAL AND AN ALLOY IN HEAT TRANSFER.

### 7.4.3. ASSUMPTIONS AND SIMPLIFICATIONS IN THE MICROSCOPIC MODELS

Bellow is listed the assumptions and the simplifications of the models:

1. When the candle is lit up, the observed heat transfer in visualized by the red color, which "propagates" in the bar. The color gradually changes from light to darker red to simulate the thermal gradient.
2. The "hot" end of the bar remains at constant temperature. This is due to the following mechanisms: (a) the heat propagation through out the material, and (b) the thermal radiation to the surrounding environment. The maximum temperature of the hot end is set arbitrary to 200$^{o}$C.
3. Three line segments depict the transient temperature. The three-line arrangement was chosen for visualization purposes. In reality the middle line in bended downwards and upwards at the two points of intercept.
4. The simulation stops when the heat has reached the other end of the rod; the candle flame freezes and the "Q" arrow stops flickering. The time required for the heat to reach the other end, at different materials, is set arbitrary for visualization purposes.
5. In microscopic models a "Q" arrow depicts heat. The "Q" arrow flickers when heat is propagating through the material and stops at the end of the simulation.
6. The microscopic models for the mechanism of heat transfer consists of a set of rigid balls arranged in a matrix form to simulate the lattice.
7. Balls depict not only the nucleus of the atom but also the core electrons. The radius of the balls thus represents the ionic radius of the element.
8. In reality, balls are much closer to each other (they should slightly overlap), as to perform bonding. In the simulations, balls are set a bit further apart for a better visualization of their vibrational motion
9. Ball movement (vibrational motion) is over-exaggerated for better visualization. In reality, the ball movement is much less.
10. Ball coherent movement (vibration in normal modes) is omitted. Balls are vibrating into two dimensions using a $A.\sin(\omega t+\varphi)$ function, where A is the amplitude of oscillation and $\varphi$ is the phase. All balls are oscillating with the same amplitude while the phase ($\varphi$) is selected randomly for each ball.
11. A simplified lattice model is used, arranging the balls in a rectangular matrix. Hexagonal lattice representations were not encountered.
12. In the amorphous material, balls are slightly misplaced from their crystalline position. This representation better describes the local ordering occurring in amorphous materials.
13. The effect of density is over exaggerated, for a better visualization.
14. The free electrons are depicted as small red balls for visualization purposes. The actual size of the electrons is much smaller compared to the nucleus plus the core electrons, than depicted in the simulations.
15. The motion of the free electrons in a metallic solid is limited within the neighborhood of 9 adjacent atoms. This is done for a better visualization: In metals, the atoms are ionised, loosing some electrons from the valence band. Those electrons form an electron sea, which binds the charged nuclei in place (metallic bond), in a similar way that the electrons in between the H atoms in the H2 molecule bind the protons.
16. In an alloy, the two different elements are depicted with different color of the balls, for a better visualization. In reality, atoms (as well as electrons) have no color.

## 7.5. THE USE OF THE "THERMOLAB" SOFTWARE

In an introductory phase, students are familiarized with experimentation and real time graphs with "ThermoLab". ThermoLab, is an Open Learning Environment, with the feel-and-look of a school laboratory, suitable for active student engagement and the application of investigative experiments. Users can quickly and easily set-up and execute experiments by direct manipulation of the objects on the computer screen and observe the results in multiple representations & graphs of temperature and heat exchange vs. time. The laboratory activities ranged from expository to problem-based investigations.

- **Topic 1:** Heat and Temperature
- **Topic 2:** Thermal Equilibrium
- **Topic 3:** The effect of thickness in Heat Flow

**Topic 1:** Heat and Temperature

**Description of the lab activities**

The Topic "Heat and Temperature" is a set of 3 Labs, shown in Figure 7.20. Lab_1 is the introductory lab in this set. Students will familiarize with the concepts, by heating up two identical beakers with water and observe the changes in temperature. In Lab_2, students will examine how the mass of water may affect the change in temperature. In Lab_3, students will examine how the heating rate may affect the change in temperature.

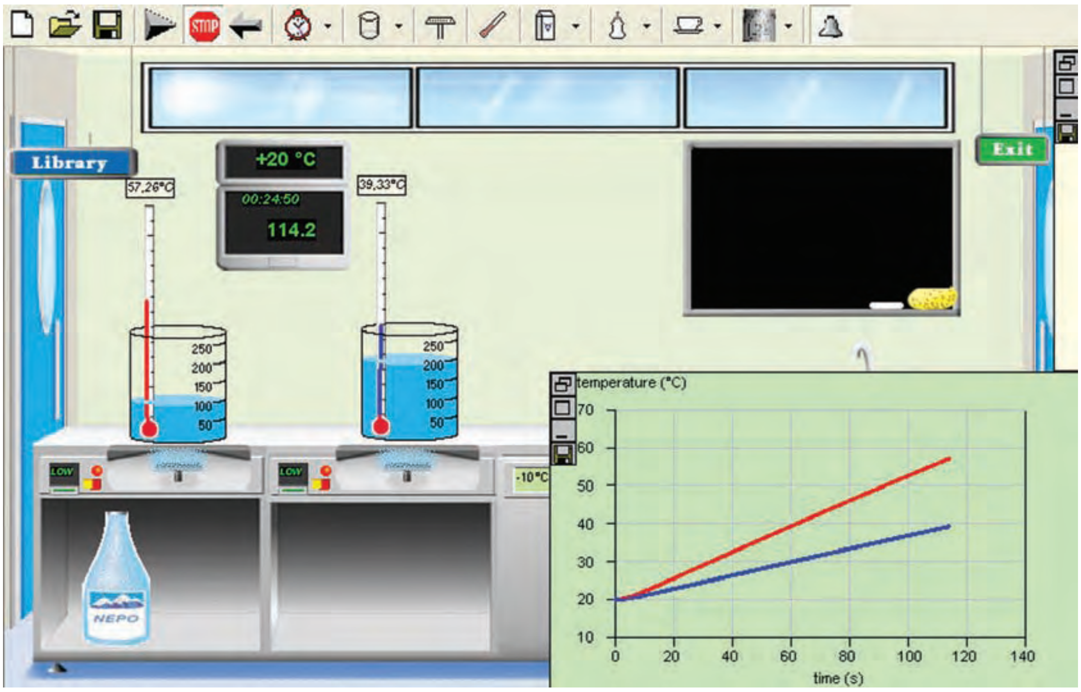



FIGURE 7.20: LAB 1 LAB ACTIVITIES IN TOPIC "HEAT AND TEMPERATURE"

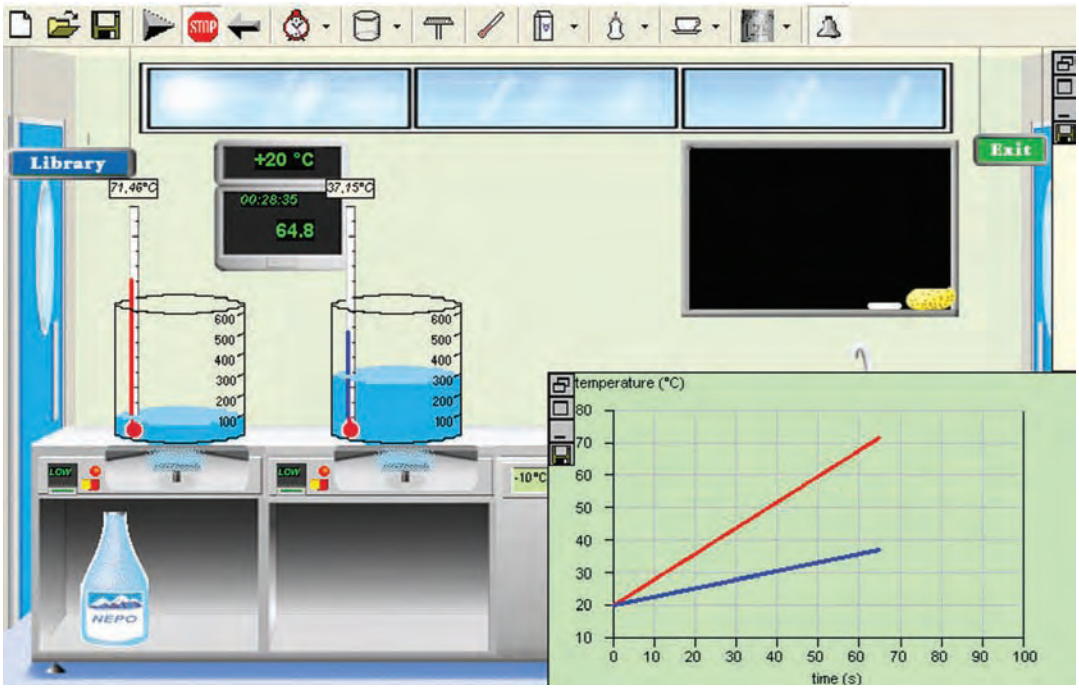



FIGURE 7.20: LAB 2 LAB ACTIVITIES IN TOPIC "HEAT AND TEMPERATURE"

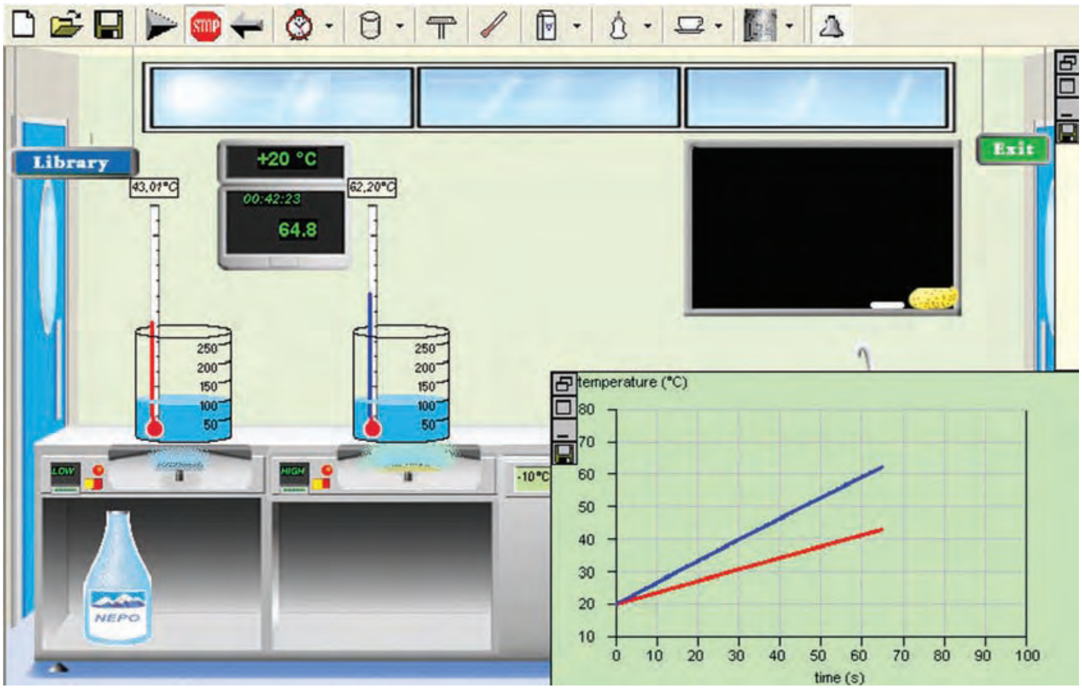



FIGURE 7.20: LAB 3 LAB ACTIVITIES IN TOPIC "HEAT AND TEMPERATURE"

**Topic 2:** Thermal Equilibrium

**Description of the lab activities**

The Topic "Thermal Equilibrium-II" is a set of 6 Labs, shown in Figure 7.21. Lab 1 is the introductory lab in this set. Students will use one thermos and a beaker to observe the conservation of heat in a closed system. In Lab 2, students will explore the heat exchange of a beaker inside a thermidometer. In Lab 3, students will explore the role of material (water/oil). In Lab 4 to Lab 6 students will explore the heat exchange in a closed system, under different initial conditions


FIGURE 7.21: LAB 1 LAB ACTIVITIES IN TOPIC "THERMAL EQUILIBRIUM"

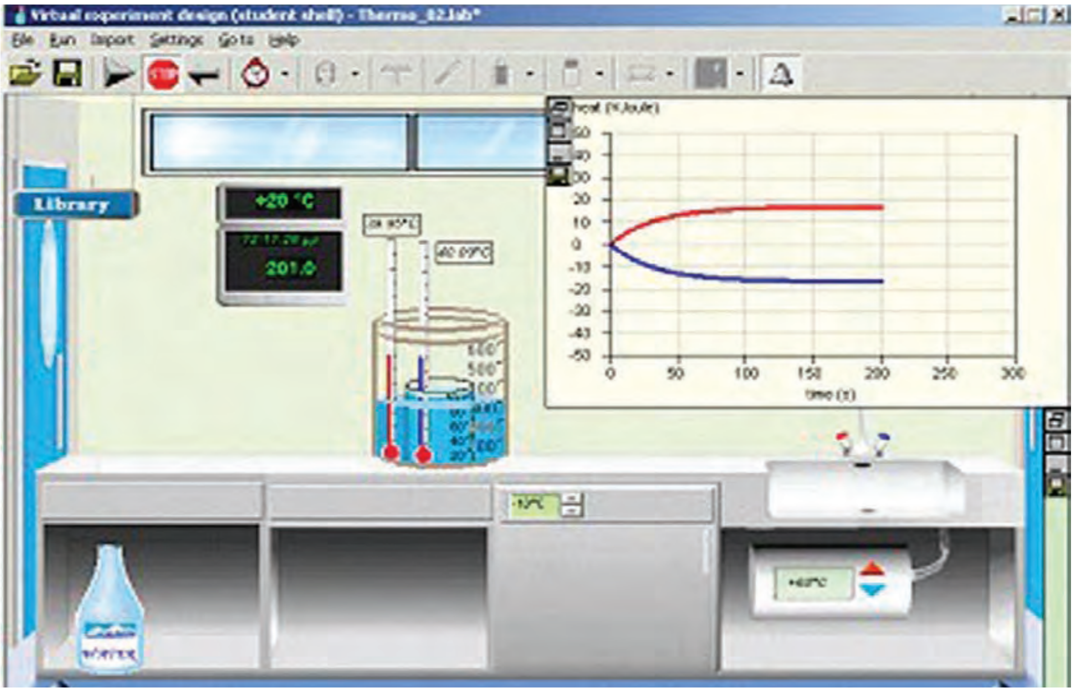


FIGURE 7.21: LAB 2 LAB ACTIVITIES IN TOPIC “THERMAL EQUILIBRIUM”

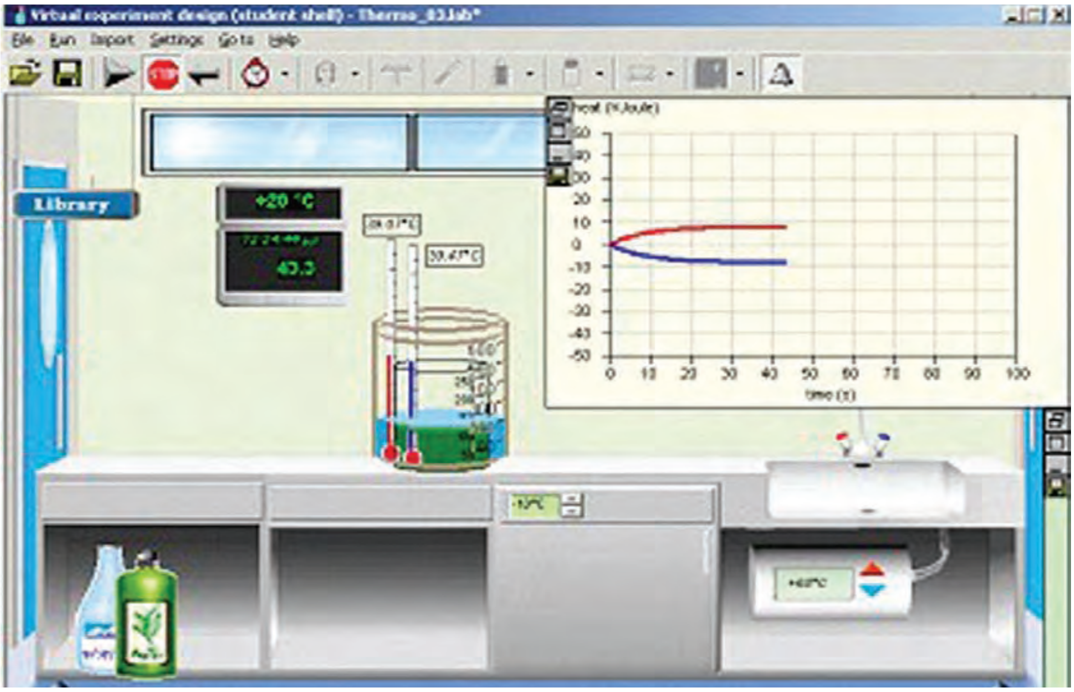


FIGURE 7.21: LAB 3 LAB ACTIVITIES IN TOPIC “THERMAL EQUILIBRIUM”

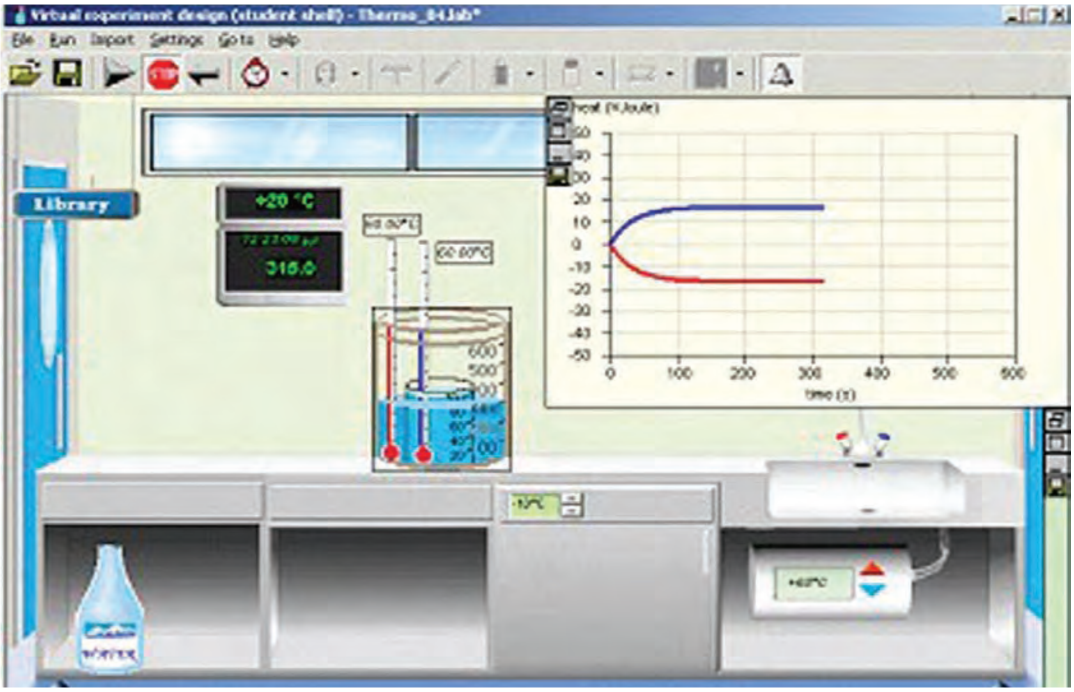



FIGURE 7.21: LAB 4 LAB ACTIVITIES IN TOPIC "THERMAL EQUILIBRIUM"


FIGURE 7.21: LAB 5 LAB ACTIVITIES IN TOPIC "THERMAL EQUILIBRIUM"

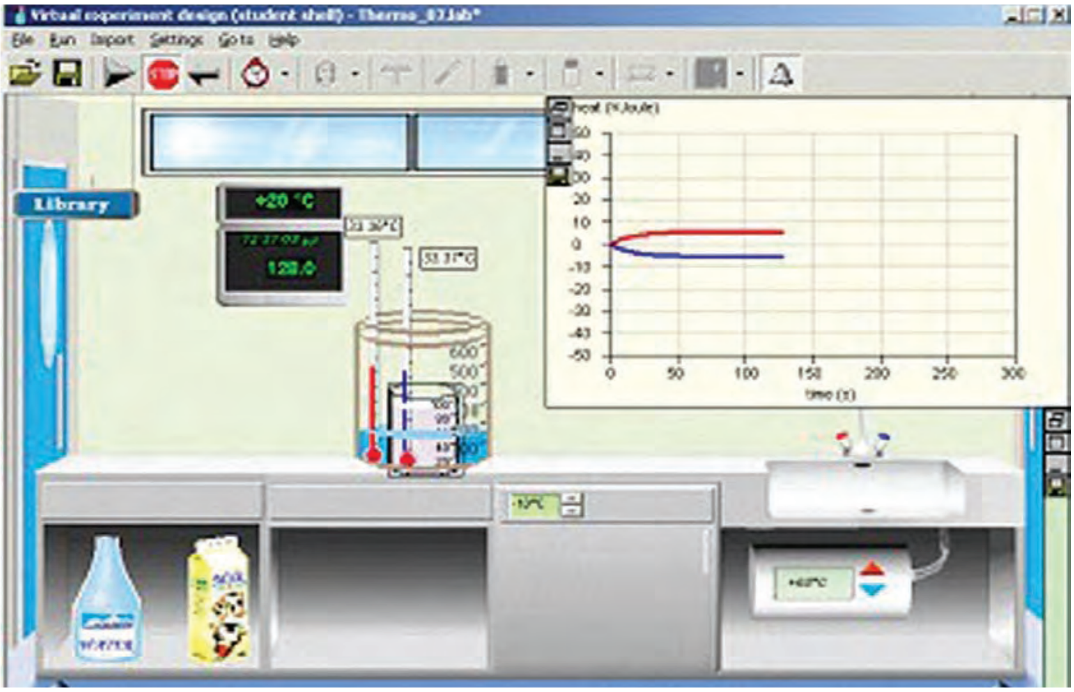



FIGURE 7.21: LAB 6 LAB ACTIVITIES IN TOPIC "THERMAL EQUILIBRIUM"

**Topic 3:** The effect of thickness in Heat Flow

### Description of the lab activities

One of the beaker properties is **thickness**, which makes ThermoLab useful for studying the heat flow for various values of thickness.

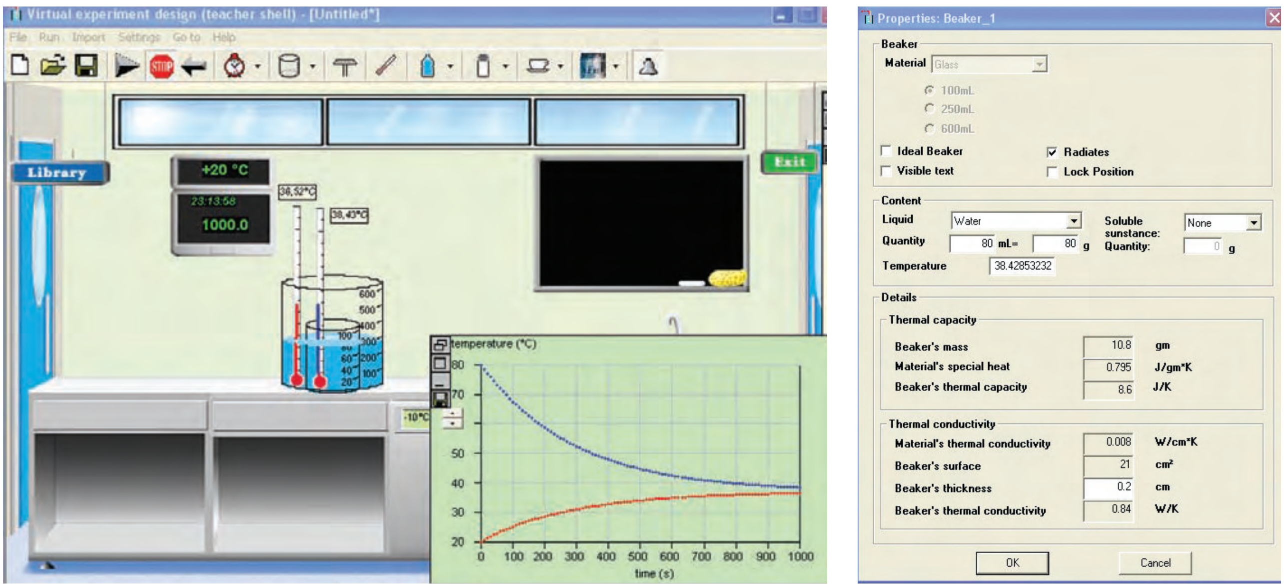



FIGURE 7.22: LAB ACTIVITY AND BEAKER PROPERTIES

# 8. COMMON STUDENT CONCEPTIONS AND DIFFICULTIES FROM RESEARCH IN SCIENCE EDUCATION

Heat phenomena, scientific concepts, models and theories, (**hereafter abbreviated as heat**) is a topic area that educators and researchers consider challenging and appropriate for primary and secondary education. The difficulty of teaching HEAT effectively to students has long been recognized by science teachers and by the science education research community. Careful attention to the choice of materials, thermal properties, phenomena, models as well as structuring of a teaching content adapted to students' minds, are necessary to produce meaningful understanding by the target population.

## 8.1. BASIC CONCEPTS

**i) Heat and Temperature**

Student and to a certain extend teacher difficulties in differentiating the concepts of heat and temperature have been extensively investigated and discussed for the last 40 years.

Young students use the terms 'heat' and 'hot' to describe their own interactions with objects, the idea of a continuous scale of 'hotness' does not develop until later. Students use the ideas of hot and cold as separate entities, and treat heat as a "substance" which moves into objects being heated (or out of those being cooled). This movement is attributed to an inherent motive force possessed by heat, or to the properties of an agent which transfer heat from one location to another.

Temperature and heat are often not differentiated and are regarded as synonymous and students often estimate the temperature of objects on the basis of the properties listed above. The intensive nature of temperature is frequently not appreciated, and students have difficulty reconciling the mathematical process of addition with the 'averaging' of temperature which occurs when, for example, water at different temperatures is mixed.

Even high school students have great difficulty with the distinction between heat and temperature as well as the particle model.

Heating concepts develop more rapidly than cooling concepts, and patterns of incorporating heating and cooling concepts are similar across cultures suggesting that domain-specific knowledge is involved in understanding these concepts.

**ii) Interactions: equilibrium and conductivity**

Students not necessarily believe that objects in thermal contact will tend towards thermal equilibrium and thus come to have the same temperature. Such a confusion is supported by the contrast between the cold sensation generated by touching good conductors (such as metals, e.g., a pan) and the warm sensation of touching insulators (such as the pan's wooden or plastic handle)

Concerning conduction students seem to be broadly familiar with ideas such "heat movement, hotness movement, heat transfer" but also use "coldness movement". However, often either they do not focus on how heat transfer occurs or provide alternative explanations for transfer mechanisms in solids liquids and gases (Engel, Clough & Driver, 1985, Sciaretta, Stilli & Vicentini, 1990). Construction of unified views on what happens in conduction is prevented by disruptive everyday experiences, for example the contrast they feel between the cold sensation generated when they touch good conductors (such as metals, e.g., a pan) and the warm sensation they feel in touching insulators (such as the pan's wooden or plastic handle).

**iii) Bodies and system**

Students do not take into account all the parts of an interacting thermal system, often neglecting the surroundings (especially the air) in their explanations. This adds to the difficulties of understanding the idea of thermal equilibrium, and makes a scientific interpretation of the cause of heat transfer more difficult to accomplish.

Since the early research studies about students' conceptions several papers have been published in the literature, which deal with the above main issues as well as details on students' conceptions as it appears from the selected references cited here (Arnold & Millar, 1994, Chang, 1999, Driver, Guesne, Tiberghien, Erickson, 1979, Erickson, 1980, Frederik, Van Der Valk, Leite, Thoren, 1999, Harisson, Grayson, Treagust, 1999, Driver, Guesne, Tiberghien, 1985, Engel, Clough, Driver, 1985, Kesidou, Duit, Glynn, 1995, Kesidou & Duit, 1993, Lautrey & Mazens, 2004, Lewis & Linn, 1994, Sciaretta, Stilli, Vicentini, 1990, McClelland & Krockover, 1996, Newell & Ross, 1996, Tiberghien, 1983)

**iv) Microscopic Models**

Research in the area of HEAT as well as in other topics show that even students at higher secondary education will face difficulties in understanding the function and the properties of microscopic models and their linking with macroscopic properties and phenomena in the area of heat e.g. the well known expansion of molecules for interpreting increase of gas volume when heated (Papageorgiou et. al, 2008)

## 8.2. ORIGIN AND DEVELOPMENT OF IDEAS

Deeper reasons for students' difficulties with the concepts of heat and tempera¬ture have been suggested from different perspectives. We point out that some researchers claim that students' concept development often parallels historical development of the same concepts (Jones, et. al, 1998, Tiberghien, 1985, Laburu, 2002, Wiser, 1986).

Other researchers take more Piagetian views of the development of these concepts, proposing maps of heat concepts through which students develop chronologically while others point out the disintegrated aptic experiences and the lack of precision in the use of the term 'heat' in everyday language. Heat is often spoken of as if it were a substance 'in' an object, and was capable of 'flowing' into other objects (Shayer, et. al, 1981, Hewson, Hamlin, 1984, Bauman, 1992, Heindel, et. al, 1969).

## 8.3. SCIENTIFIC AND TEXTBOOK MODELS

Heat and temperature concepts are also challenging to scientists, who may make more accurate predictions than students, but who also have difficulty explaining everyday phenomena in interviews), and who maintain divergent representations in their writing. (Sciaretta, Stilli, Vicentini, 1990, Cotignola, Bordogna, Punte, Cappannini, 2002).

We may also note that textbook analysis shows inconsistencies in the use of terms and application of models to interpret phenomena and this may contribute and/or strengthen students' alternative conceptions in HEAT. The issue of appropriate treatment and the meaning of heat in relation to other concepts as internal energy continuous to draw attention of science educators and deabates in the literature as appears from the selected papers referred here (Leite, 1999, Allen, 1983, Antoniou, Baladakis, Dimitriadis, Papamihalis, Papatsimpa, 2000 (in Greek), Barnes, 1999, Karapanagiotis, Papastamatiou, Fertis, Haletsos, 1998 (in Greek), Leite & Laurinda, 1999, Mak, Se-Yuen, Young, Kenneth, 1987, Reif, 1999, Vaquero, Santos, Andres, 2001, Zemansky, 1970, Warren, 1972).

## 8.4. TEACHING APPROACHES

Several studies have been published about teaching heat concepts and phenomena. Research based innovative approaches in the topic of Heat and Temperature focus on helping students construct their understanding of the concepts heat and temperature and their differentiation. Several of them are based on constructivist approaches (Thomaz et al. 1997, Rosenquist, Popp, McDermott, 1982, Taber, 2000, Alonso & Finn, 1995, Arnold & Millar, 1996, Baser & Geban, 2007, Carlton, 2000, Gonzalez-Espada, Wilson, Bryan, Lynn, Kang, Nam-Hwa, 2001, She, Hsiao-Ching, 2003, She, Hsiao-Ching, 2004). Other researchers focus on helping students understand thermal equilibrium as a central organizing concept in this topic (Arnold & Millar, 1997), or attempt to construct frameworks for teaching heat (Rogan, 1988). Liew, Chong Wah & Treagust, (1995) suggested a sequence for learning about understanding of heat and expansion of liquids based on predict-observe-explain strategy; Hausfather, Samuel (1992) focus on conceptual change; Hewson & Hamlyn, (1983), on the influence of intellectual environment on conceptions of heat; Jones, Carter, Rua, (2000), explore the development of conceptual ecologies related to convection.

Clark & Jorde (2004) analyzed the impact of an integrated sensory model within thermal equilibrium visualizations. Linn and colleagues (1996) focused on students' integration of experiential and scientific concepts by employing a macroscopic heat flow model; however, Wiser & Amin, (2001) have argued that understanding microscopic mechanisms helps students to differentiate the concepts of heat and temperature.

In several of these studies, in addition to usual experiments, ICT based materials have been used, which result in powerful learning environments concerning heat phenomena , which have opened up new learning opportunities for the students (Linn, 1995, Linn, & Hsi, 2000) and open new ways for data handling Drago, (1993). Simulations and virtual labs provide facilities to visualize phenomena and concepts as well as to link experiments with underlying scientific theories (Hatzikraniotis, et. al, 2001, Petridou, et. al 2005, Windschitl, Andre, 1998, Windschitl, 2001, Bisdikian and Psillos, 2002).

## 8.5. ABOUT MODELS AND MODELING

Models are powerful teaching tools which may contribute both to students' cognitive evolution and to effective learning (Saari & Viiri 2003). Schwarz & White, (2005), Scwarz, (2002) argue that without metamodeling knowledge, students cannot fully understand the nature of science, and their ability to use and develop scientific models will be impeded. Research underlines that teachers' knowledge on the nature of models and their fundamental characteristics is limited (Van Driel & Verloop 1999, Harrison, 2001). Research, also, indicates that although students may successfully engage in creating scientific models as part of inquiry-oriented science curricula, neither students nor their teachers possess much knowledge about the nature and purpose of scientific models (Carey & Smith 1993, Grosslight et. al, 1991, Treagust, Chittleborough, Mamiala, 2002).

Concerning models there is a growing interest in developing and applying innovative approaches aiming at facilitating teachers' understanding on models in describing or predicting natural phenomena and potentially apply modelling procedures to their classes (Justi & Van Driel, 2005, Besson, Viennot, 2004, Papaevripidou, Hadjiagapiou, Constantinou, 2005, Gobert, Buckley, 2000). However, research shows that students and teachers face difficulties in understanding the concept of models and their use, particularly its predictive function, even after participating in innovative model-based teachings (Crawford & Cullin, 2004, Harrison, 2001, Seel, 2003, Van Driel & De Jong, 2003).

## 8.6. ABOUT EXPERIMENTAL WORK

Finally, experimental investigations imply that students are not only learning science but they are also involved in 'doing science', which is distinct from the mere possession of laboratory skills of manipulation, on the one hand, and the possession of certain conceptual understanding, on the other (Psillos, Niedderer, Eds., 2002, Watson, et. al., 1995). The new ICT tools enrich laboratory work (Russell, et. al, 2004, Smyrnaiou, et. al, 2004)

The ability to design experiments is considered to be one of the most important of those skills linked to laboratory investigations (Johnstone & Al-Shuaili, 2001). According to Garratt & Tomlinson (2001), this skill is considered to be even of greater importance than the actual execution of an experiment, as it is not only related to the content under study but to scientific methodology as well. Designing an experiment is the 'thinking part' of experimental inquiry including several dimensions such as identifying a particular issue or problem for investigation, formulating a hypothesis and defining the dependent and independent variables, fitting a particular experimental procedure to the proposed investigation. Designing is an aspect of 'doing science' that can only be gained by experience either in traditional or simulated laboratories. Assessment of students' mastery of design of experiments, even at a University level has indicated that students have limited understanding of the process of design and of fundamental concepts such as definitions of dependent and independent variables as well as of distinguishing possible methods of measurement (Anagnos, 2007). Researchers are recently investigating proposals for facilitating experimental design by students through various guided approaches including the gradual shifting from relatively closed experimentation to more open situations in which students themselves identify dependent and independed variables and suggest experimental procedures.

## 8.7. IDEAS FOR EXPERIMENTS AND ACTIVITIES

In a number of papers we can note a wide variety of innovative ideas and suggestions for new experiments and applications of basic concepts in a variety of situations and technological artefacts. Selected references are fully presented in the end of the teachers guide. Here we mention them Bacon, Michael et. al., 1995, Cavallo, 2001, Ebert, Elliott, Hurteau, Schulz, 2004, Economides & Maloney, 1978, Edge, 1993, Knight, Wohlhagen, McIldowie, 1998, Pynadath, 1978, Ramondetta, 1994, Ruck et. al., 1991, Rushton, Ryan, Swift, 2001, Stinner, 1978, Switzer, 1984, Taylor, 1989, Wang & Grossman, 1987, Ward, 1973, Widick, 1975, Wolfgang & Belloni, 2003.

# 9. MONITORING STUDENT LEARNING

Instruments for Assessing Learning Outcomes
The assessment tasks are designed to validate the module's activities, probing if the intended learning objectives have been substantiated in students' learning outcomes. Pre test and post questionnaires have been developed. The post test questionnaire includes pre test tasks and additional ones which are related to the taught knowledge. It is expected that students demonstrate an understanding of the addressed issues:

a) That different materials conduct heat differently (some materials conduct heat faster than others).
b) Heat conduction and the microscopic explanation of the phenomena observed.
c) The parameters affecting heat conduction in matter (theoretically and experimentally introduced to students).
d) How the above can be applied in everyday life situations.

The assessment tasks investigate whether students are able to interpret the observed phenomena, explore simple models, design simple experiments with common materials to cope with everyday problems. Student assessment also focuses on the transfer of acquired knowledge and skills in contexts that students were previously unfamiliar with.

## 9.1. MONITORING STUDENT'S CONCEPTUAL UNDERSTANDING

To investigate students' conceptual gains a pre-post test approach was adopted.

Questionnaire items can be organized in the following themes:

- Thermal equilibrium of bodies and their environment.
- Microscopic explanation of thermal conduction through matter.
- The role of the environment in the insulation procedures.
- Thermal conductivity of different materials
- Ranking materials depending on their thermal conductivity.
- Parameters such as density, area and thickness, affecting heat conduction.

Qualitative analysis of the students' written documentation was employed. The procedure used identification of regularities in the first stage followed by a constant comparative technique. Comparative analysis of the pre and post test findings produced results on students learning achievement.

Data collected by these questionnaires were supplemented by semi-structured interviews conducted by the teachers after the students had completed the questionnaires. These interviews were based on the questionnaires as well as on students' interpretation of on line running of the microscopic simulations. Besides a series of worksheet assignments carried out individually by the students provided additional data for the evolution of students during teaching.

## 9.2. MONITORING STUDENT'S ABILITIES TO DESIGN EXPERIMENTS

It was decided that students' ability to design experiments would be tested only at a post-instructional level, since these students had no previous experience in this domain. The main source of data was a post-instructional questionnaire: One of the questionnaire items was designed to evaluate the experiment design skills acquired by the students: Specifically, students are asked to deal with a real-life problem situation. In fact what we are asking the students to do was to express hypotheses and plan an investigative process to verify them.

The questionnaire was analysed for aspects of students' ability in experimentation.

## 9.3. MONITORING STUDENTS' UNDERSTANDING ABOUT MODELS

To investigate students' conceptual gains about models a pre-post test approach was adopted.
The pre-post tests were focusing on two main aspects of models. Specifically, four questions were used for the aim of the study:

- The first and the second question of the pre and the post-test of models refer to the nature of models, which means that through these questions we investigate the students' ideas about what a model represents and if it represents the reality exactly as it is.
- The third and the fourth question refer to the purpose of the model, which means that through these questions we investigate the students' ideas

about the use of models and if they consider that the model is a powerful research tool.

## 9.4. MONITORING STUDENT ENGAGEMENT AND MOTIVATION

To investigate Students' engagement in the proposed inquiry activities and motivation towards learning science, two questionnaires were developed by the Finish group was used:

A 24-items questionnaire (Q1) which requests the students to evaluate how well each item corresponds to the reasons why they learn science.
A second questionnaire (Q2) developed to investigate the features which arouse and maintain and channel students' behaviour towards the science inquiry activities. This investigation is performed before and after the teaching. In this way it is possible to compare the inquiry activities carried out in the Module with laboratory activities usually carried out at school. In this questionnaire the students are asked to evaluate how well 29 items correspond to their perception of inquiry/laboratory activities. From the comparison it can be plausible to infer how motivating the designed module's activities were.

# B: DESCRIPTION AND ANALYSIS OF STUDENT ACTIVITIES

# B: DESCRIPTION AND ANALYSIS OF STUDENT ACTIVITIES

## UNIT 1: THERMAL CONDUCTIVITY OF MATERIALS

### 1.0. OBJECTIVES OF THE UNIT:

- The students will study the thermal interaction between two equal quantities of water having the same temperature in cups made of different materials, during their cooling down.
- The students will rank the materials used, according to their thermal conductivity.
- The students will use experimental evidence to decide on an everyday problem.
- The students will work in groups in order to carry out an experimental investigation.
- The students will reflect on the purpose and nature of experimental activities they carried out in the unit

### 1.1. DURATION OF THE UNIT:

1 teaching hour

### 2.0. CLASS ORGANIZATION:

Students collaborate in teams in front of each experimental setup. There are 3 different experimental sets[1]. Therefore, the students are split in 3 or more groups. If the number of students permits it, ($n_{group} > 5$ or $n_{class} > 15$), then there may be two teams assigned to each experimental set.

### 2.1. MATERIALS:

2 similar cups: 1 made of glass and 1 made of plastic (Group A) or 1 made of glass and 1 made of metal (Group B) or 1 made of plastic and 1 made of metal) (Group C), 2 small glass basins, 2 laboratory thermometers, chronometer, water.

**Teaching notes:**

### 3.0. AN EVERY DAY SITUATION (A)

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| One day in school the students encounter the following problem:<br><br>"A cold winter day, you went with your friends to the school buffet and ordered hot chocolates to drink. The drinks had the same temperature and were served in different cups.<br><br>• Which cup of hot chocolate would you choose, in order to be able to hold it without getting burned?"<br>The glass, Metal or the Plastic cup?<br>Give a brief explanation regarding your choice.<br><br>• After a while, in which cup would the chocolate cool down faster?<br>Give a brief explanation describing your point of view" | The students in preceding lessons noticed that heat is transferred from hot water, contained in a vessel, to the environment. Thus, after a while, the hot water in the vessel will cool down.<br><br>This question elicitates students' views regarding the role of materials the vessels are made of in an every day context. The teacher carries out a discussion to prompt the students to think of this familiar every day problem situation.<br><br>After individual prediction by each student the teacher coordinates a short discussion in order that the students reflect and announce their predictions to the class. Relevant questions may be as following:<br><br>• Which cup will cool down the faster (which is more conductive)?<br><br>• Which cup will cool down the slowest (more insulating material)? |

1. *Separate worksheets (WS) should be printed for each team, the only difference being the materials: WS for Group A uses glass and plastic cups, WS for Group B uses glass and metallic cups and WS for Group C uses plastic and metallic cups.*

### 3.0. AN EVERY DAY SITUATION (B)

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| | When asking, the teacher may provide clarifications, but no hints to the correct answers.<br>At the end the teacher states to the students that, from a scientific point of view, their predictions may be accepted or rejected by experimental evidence.<br>He also outlines the experimental method that will be followed in the unit in order to collect evidence and find out answers. |

### 3.1. PREPARATION OF THE EXPERIMENT AND

### 3.2. PREDICTION

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students get familiar with the experimental sets, measure the temperature of the two quantities of hot water in the two similar cups and provide a short answer to the prediction question, without any justification. | The students are given only the set of cups that they will experiment with. They should not spend much time for these preparatory activities: after they take readings of the temperatures of the two quantities of hot water (preferably two students could do it simultaneously), they should reply to the prediction question and start carrying out the experiment. |

### 3.3. EXPERIMENTATION TO CHECK PREDICTION (A)

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students study the WS in order to organize their activity and assign roles within the team (who will measure temperature, who will measure time, who will record data etc.). | The teacher has to prepare hot water before the start of the unit. Hot water should be above 80 °C so that during the usual initial time delays (providing instructions to students, etc.) its temperature does not fall under 70 °C.<br>The teacher should take care that the temperature of water in the cups and the temperature in glass basins **is the same. Temperature may vary from group to group, but NOT within a group.**<br>In case the teacher opts to use different size heating beakers than the ones suggested, he should take care the quantities of water used result into the same water levels in the inner heating beaker and the (outer) small glass basin. |

## 3.3. EXPERIMENTATION TO CHECK PREDICTION (B)

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| | The teacher supervises, and if needed, co-ordinates organisation of work by the teams. He asks the students to plan in advance the activities they are about to carry out during the experiment. Each student should be aware of his role in the group and what he is expected to do in each phase of the experiment. |
| The students measure the temperature of the water poured in the 2 cups by the teacher.<br><br>The students place each cup, along with its thermometer, in a small glass basin and then leave the quantities of hot water in the cups to interact with the colder water of the basin.<br><br>The student operating the chronometer should announce time every 0.5 min (they should get familiar with its operation to not accidentally reset it).<br><br>The students measure the temperature of the water in the cups every 0.5 min, fill in Table 1 and answer the questions of the worksheet. | The teacher should remind the students that:<br><br>• They should keep the two thermometers immersed in the water at the same depth, taking care they don't touch the walls of the cups and that they are not accidentally displaced by the students.<br><br>• The students should be constantly monitoring the thermometer and be ready to announce temperature readings when asked.<br><br>The teacher acts as facilitator and assists in experimentation.<br><br>The students are expected to observe an initial rapid fall of the temperature in the two cups. Temperature values will converge fast in the beginning and then, at a slower rate, all water temperatures will gradually approach room temperature.<br><br>When the first such convergence becomes obvious, the teacher should ask the students to stop data collection – it is not necessary to fill in all the rows of the Table up to 10 minutes. |
| Each group announces their results to the class.<br><br>Whole classroom discussion | The teacher collects and organizes students' results in the appropriate table (see APPENDIX I: Table). It is suggested that he also prints the blank table on a transparency, as well as the results page, to be able to fill in the results directly on the overhead. |

### 3.4. COMPARISON OF THE PREDICTIONS TO THE RESULTS OF THE EXPERIMENT AND CONCLUSIONS

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| Students compare the result of the experiment to their experimental predictions and proceed to identify and justify any differences.<br><br>Students discuss the group results and compare the materials regarding their thermal conductivity. | The teacher coordinates the discussion and helps students to draw conclusions regarding the thermal conductivity of the three materials. He also identifies and discusses any possible differences in experimental data between the teams.<br><br>If the teacher finds it useful, he may print and complete the results page (see APPENDIX II: Conclusions) on the overhead during the discussion and the drawing of conclusions by the students. |

### 3.5. APPLICATION TO THE EVERYDAY SITUATION

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students attempt to construct links between the experiments and the everyday situation, reflect on their predictions taking into account experimental evidence in order to accept or reject it. | The teacher facilitates the construction of links by the students between the experiments and the everyday situation, discusses the methodology and prompts the students to accept or reject their predictions on the basis of experimental evidence. |

### 3.6. EXTENDED ACTIVITIES

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students handle these questions either orally in the classroom or in writing at home. | The teacher prompts the students to think and reflect:<br>• on what was the scientific question they attempted to answer experimentally during the lesson,<br>• on the steps and activities they went through,<br>• on what constitute the scientific way to find answers.<br><br>Such questions help students to think of aspects of experimental design. It is up to the teacher to decide whether and how will handle these tasks. |

## APPENDIX I

TABLE 1

| | 1ST GROUP | | 2ND GROUP | | 3RD GROUP | |
|---|---|---|---|---|---|---|
| TIME | GLASS | PLASTIC | GLASS | METAL | PLASTIC | METAL |
| Initial | | | | | | |
| 0.5 min | | | | | | |
| 1 min | | | | | | |
| 1.5 min | | | | | | |
| 2 min | | | | | | |
| 2.5 min | | | | | | |
| 3 min | | | | | | |
| 3.5 min | | | | | | |
| 4 min | | | | | | |
| 4.5 min | | | | | | |
| 5 min | | | | | | |
| 5.5 min | | | | | | |
| 6 min | | | | | | |
| 6.5 min | | | | | | |
| 7 min | | | | | | |
| 7.5 min | | | | | | |
| 8 min | | | | | | |
| 8.5 min | | | | | | |
| 9 min | | | | | | |
| 9.5 min | | | | | | |
| 10 min | | | | | | |

**APPENDIX II** (Transparency)

## CONCLUSIONS

### GROUP 1

- The water in the ………………… cup **cools down faster** than the water in the ……………… cup.
- Therefore, ………………… transfers heat faster than …………………

### GROUP 2

- The water in the ………………… cup **cools down faster** than the water in the ……………… cup.
- Therefore, ………………… transfers heat faster than …………………

### GROUP 3

- The water in the ………………… cup **cools down faster** than the water in the ……………… cup.
- Therefore, ………………… transfers heat faster than …………………

### RANKING OF MATERIALS ACCORDING TO THEIR THERMAL CONDUCTIVITY

**MOST THERMALLY CONDUCTIVE:** …………………………………………………

**INTERMEDIATELY THERMALLY CONDUCTIVE:** …………………………………………………

**LEAST THERMALLY CONDUCTIVE:** …………………………………………………
**OR MOST THERMALLY INSULATING**

## UNIT 2: TEMPERATURE AND THE MICROWORLD

### 1.0. OBJECTIVES OF THE UNIT:

- The students will explore a microscopic model for temperature in ceramics.
- The students will explore a microscopic model for temperature in metals.
- The students will compare microscopic modes for temperature in ceramics and metals.
- The students will work in groups in order to get familiar with and explore simulated microscopic models.
- The will reflect on the nature and use of models in science.

### 1.1. DURATION OF THE UNIT:

1 teaching hour

### 2.0. CLASS ORGANIZATION:

Students work in teams.

### 2.1. MATERIALS:

Computer Simulation: Microscopic Models: Lab 1

**Teaching notes:**

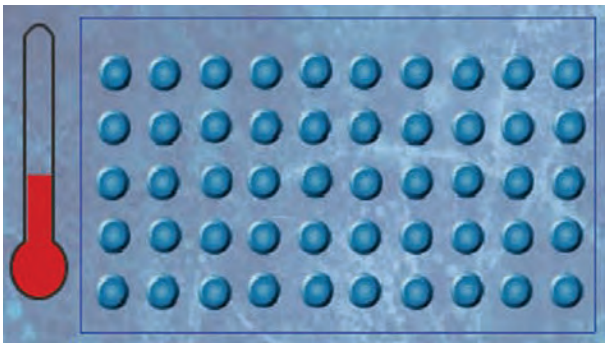
### 3.0. ELICITATING STUDENTS' VIEWS

| STUDENT ACTIVITIES | TEACHER COMMENTS |
| --- | --- |
| The students have to express their point of view on the following question:<br>"In the previous lab, we observed that the temperature of hot water in the metal cup was falling faster than in the plastic one. Thus, we concluded that metals CONDUCT heat faster than plastic.<br>Why this is the case? What do you think really happens?"<br>Why is this explanation important for us?" | The students in the previous unit saw that the temperature of hot water in the metal cup was falling faster than in the plastic cup.<br>This task aims to elicitate how students make sense of the experimental outcomes they witnessed in the previous unit. It may provide valuable information to the teacher as well as to engage the students in quest for explanation and their value. |

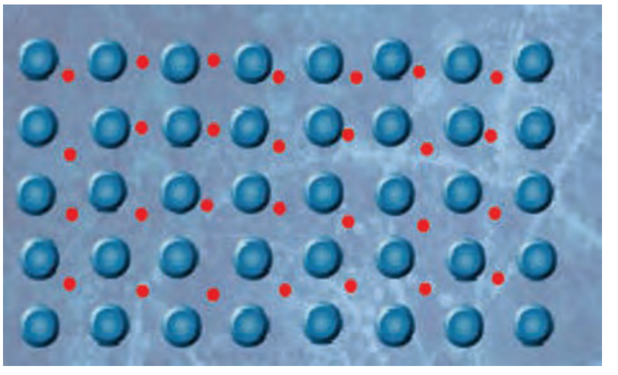
### 3.1. THE SCIENTIFIC CONCEPTUALIZATION: THE MICROWORLD

#### A. CERAMICS AND THEIR STRUCTURE

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students read and discuss the text in the worksheet. | The teacher reminds students what they have been taught about temperature and microworld in preceding lessons before the module and in chemistry. The teacher discusses the text and draws on examples of ceramics around us. He takes care to distinguish between specific objects, like a water glass, the material, glass, and the category, ceramics, which includes several materials. |
| **Observation and exploration of a Model for ceramics.**<br>The students observe the picture write their descriptions and are involved in guided observation of this model.<br><br>Guided observations and manipulation of simulation by the students. | The teacher introduces the concept of scientific model. Initially, the students observe a static picture of lattice for ceramics. Care is taken to discuss that the picture represents the lattice. Specific questions guide students' observation of the shape and structure of lattice.<br>In activity 3.1.2 the students get involved in the first simulation and the teacher should clarify the meaning of a "simulation". He should emphasise that it is a representation, of the structure of these materials visualizing scientific models. He also should emphasise some features of what is shown on the screen e.g true dimensions of what is depicted. The small blue balls represent the particles in a (ceramic) material; therefore they actually represent only an infinitely small fraction of the rod's length.<br>These remarks, as well as similar ones that may emerge in the next simulations e.g. the representation of electrons, should be frequently mentioned by the teacher. The reason is that although simulations are very useful to represent phenomena, they may at the same time easily generate misconceptions, in case their underlying assumptions are not made explicit and frequently clarified. |
| **Exploration of the model.**<br>The students run simulation "Microscopic", then run "Lab1" and choose "Step A1".<br>They observe the running of the simulation. | The teacher facilitates the students to "play" with this model and construct the following conclusion: the more the temperature of a crystalline ceramic rises, the more the particles of the material oscillate. This is an important feature of this simulated model which is visually observable. |

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| <br>FIG. 2.1<br><br>By pressing the right arrow, students observe the particle oscillate in a crystalline ceramic material at a low temperature.<br><br>By following the instructions on the screen, they are guided to observe the influence of temperature on the oscillation of the particles.<br><br>Students raise the temperature and observe what happens at higher temperatures. | The teacher should take special care to assist the students in observing the way the particles oscillate, i.e. whether they all move simultaneously towards the same direction or whether they move randomly.<br><br>The teacher prompts the students to carefully study, discuss and write answers when required, to identify the differences between the static and the dynamic representation of the lattice model so that the students are introduced in the idea of several representations of a model as well as the relative merits of a simulation.<br><br>The teacher prompts the students to hypothesize if and how they could manage to "stop" the continuous movement of particles and what would be the implications for temperature.<br><br>Finally, the teacher coordinates the discussion to help students link the oscillation of one particle to its kinetic energy and then to the kinetic energy of the whole of the material. |
| **Conclusion**<br><br>The students fill in the questions of the WS in conclusions 3.1.3 related to:<br><br>- the construction of a conclusion regarding how temperature relates to the oscillation of the particles.<br>- the total kinetic energy of the mass of the material when its temperature is gradually increased. | In Conclusion 3.13 the principal aim is to help the students realize that the "increase of temperature" in a material means an "increase of the kinetic energy of its particles".<br><br>The teacher coordinates class discussion so that the students are able to write down their answers to the questions of the WS. |

## B. METALS

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students, still in the SAME simulation, choose "Step A2".<br><br>They read and discuss with the teacher the short text about free electrons and relate this knowledge to what they have been taught in chemistry.<br><br>**Observation of the Model**<br><br>The students observe the internal structure of metals, focus their attention on the motion of the free electrons and answer to the questions of the WS. | This simulation of the structure of metals aims to facilitate the students to visualize their crystalline structure as well as the movement of free electrons.<br><br>The following clarifications are made by the teacher:<br><br><br><br>FIG. 2.2<br><br>i) Electrons are depicted disproportionally larger than the lattice ions.<br>ii) Electrons are depicted in red only to facilitate the observation of their motion relative to the blue particles.<br>iii) Electrons move ONLY in the space between neighbouring particles.<br><br>The teacher should point out and emphasise the above assumptions, in order to prevent the creation or reinforcement of misconceptions, not only before using the simulations, but whenever he finds a suitable opportunity. |
| **Exploration of the model.**<br><br>Guided observations by the students. The students play with temperature change, note the effects on oscillation, and relate the continuous motion of electrons to the heat transferred macroscopically to the metal.<br><br>Students comment on the simulation and complete their WS, answering to the questions posed. | The teacher focuses students' attention and asks them to observe and comment on:<br><br>i) the oscillations of particles on the lattice before and after the rise of temperature;<br>ii) the motion of electrons, before and after their "collisions" with the oscillating particles of the lattice;<br>iii) the motion of the electrons at the 1st column compared to the motion of the electron at the last column.<br><br>The teacher helps students to express their replies using the appropriate scientific terms. |

### 3.2. CONCLUSIONS

| STUDENT ACTIVITIES | TEACHER COMMENTS |
| --- | --- |
| Finally, students compare the results from the two simulation runs and then draw conclusions and write down their view, thus providing valuable feedback to the teacher. | The teacher discusses and points out the differences in the heat conduction in ceramics and in metals. |

### 3.3. DISCUSSION ABOUT MODELS

| STUDENT ACTIVITIES | TEACHER COMMENTS |
| --- | --- |
| The students discuss and /or write their replies either in teams or in whole classroom. | This is an important metacognitive activity in which the teacher should try to engage the students in either writing or discussing about the difference of the various representation as well as what was their value for the students. |

### 3.4. EXTENSION

| STUDENT ACTIVITIES | TEACHER COMMENTS |
| --- | --- |
| The students handle these questions either orally in the classroom or in writing at home. | The teacher handles these questions either orally in the classroom or in writing at home. In this unit there are several extended activities which mainly should be handed out to the students in order to fulfil them at home.<br><br>Questions 5.1, 5. 2, 5.3, 5.4 aim to prompt the students use the simulated model to draw conclusions, think of its limitations and that is not a copy of reality and its value for them as a heuristic tool.<br><br>Q5.5 is for home and for linking what was done in the classroom with resources from the web as an extended activity. |

# UNIT 3: HEAT CONDUCTION IN CERAMIC MATERIALS AND METALS

## 1.0. OBJECTIVES OF THE UNIT:

- The students will get familiar with and use simulated microscopic models in order to make sense of macroscopic phenomena.
- The students will recognise the role of the oscillation of particles of the lattice in heat conduction in ceramics and in metals.
- The students will recognise the role of free electrons in heat conduction in metals.
- The students will interpret heat conduction in ceramic materials and in metals at the microscopic level.
- The students will be read, discuss and reflect upon t the nature and use of models.

## 1.1. DURATION OF THE UNIT:

1 teaching hour

## 2.0. CLASS ORGANIZATION:

Students, after the demonstration experiment, collaborate in teams of two and run computer simulations.

## 2.1. MATERIALS:

Computer simulations: Microscopic simulation Lab 4

**Teaching notes:**

## 3.0. DEMONSTRATION EXPERIMENT

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| Before observing the demonstration experiment, the students reply individually to the written Prediction Question:<br>*"From the glass (ceramic) or from the iron (metal) rod, will the wax fall off first? Please Justify your answer.*<br>*Try to imagine what happens in the microworld and justify your answer."*<br>During the experiment, the students discuss with the teacher about their expectations. | The teacher describes the demonstration experiment the students are about to observe and asks them to write down their prediction about the results of this experiment.<br>Then he carries out the experiment. During the heating of the rods, he discusses with students their expected outcome. Besides, he prompts the students to think whether this activity could be related to an everyday experience. |
| The students participate in the whole classroom discussion | Approximately 5 minutes are required for the wax to fall off the metal rod. Chances are that the wax will not fall off at all from the glass rod during the class period. The glass rod gets heated only locally at its end, while heat does not appear to propagate to the other end of the rod.<br>As soon as the wax falls off the metal rod, the teacher discusses the result, points out that time is different for the wax to fall off. He prompts the students to think of their prediction and wonder why this happens. He notes that glass is ceramic and not metal. He also tries to make them think of what possibly could happen in the microworld. |

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students are engaged in reflection about their prediction and argumentation about their views with their classmates. | He draws on some other objects in both categories and then proceeds to explain what is the use of a simulation for providing an interpretation for this experimental result.<br><br>The teacher may proceed to Part B, without waiting to see what happens to the glass rod. During the remainder of the unit, the teacher can occasionally point out that the wax on the glass rod is still in place. |

### 3.1. SCIENTIFIC APPROACH I: WHAT HAPPENS IN CERAMICS

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students run the simulation "Microscopic Model", proceed to "Lab4" and then choose "StepA1".<br><br>In the beginning, the students observe the simulated evolution of the phenomenon by pressing "Play". The rod gets heated at its one end and gets glowing red hot. Heat is transferred to the other end of the rod. Each thermometer on the rod indicates a gradually increasing temperature, while at the same time, the further each thermometer is located from the heated end, the lower its temperature reading becomes.<br><br>Then students choose "Microscopic" and after resetting the heated rod to its initial state by pressing "Reset", they observe the phenomenon once more, but at a microscopic level.<br><br>The students observe the simulations and record their observations on the WS. Special care should be taken when comparing the oscillation of the particles in the 1st and the last column of the material. | Initially the teacher should clarify again the meaning and use of a "simulation[2]". He should emphasise that it is a representation, made as simple as possible, of the process that take place visualizing scientific models. He also discusses multiple representations on the screen.<br><br>He also, again, should emphasise the true dimensions of what is depicted on the screen. The small blue spheres represent the particles in a material; therefore on the screen is represented only an infinitely small fraction of the rod's length.<br><br>These remarks, as well as similar ones that may emerge in the next simulations e.g. the representation of electrons, should be frequently noted and enhanced, either by the teacher, or by the students when answering questions. The reason is that although simulations are very useful to represent phenomena, they may at the same time easily generate misconceptions, in case their underlying assumptions are not made explicit and frequently clarified.<br><br>The teacher then asks students to answer the questions of the WS and specifically to compare the oscillation of the particles in the 1st and the last column of the material. |
| At the end, in 3.1.3 the students are asked to construct conclusions on the process of heat conduction in ceramic materials. | In 3.1.3 he guides the discussion and helps the students to express their thoughts based on the model regarding how heat conduction happens in ceramic materials. |

2. *NOTE: The simulations and the related assumptions are presented analytically in the description of the resources.*

## 3.2. SCIENTIFIC APPROACH II: WHAT HAPPENS IN METALS

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students proceed to “Step A2”.<br><br>In the beginning, the students observe the simulated evolution of the phenomenon by pressing “Play”. The metallic rod gets heated at its one end and gets glowing red hot. Heat is transferred to the other end of the rod. Each thermometer on the rod indicates a gradually increasing temperature, while at the same time, the further each thermometer is located from the heated end, the lower its temperature reading becomes.<br><br>Then students choose “Microscopic” and after resetting the heated rod to its initial state by pressing “Reset”, they observe the phenomenon once more, but at a microscopic level.<br><br>The students observe the simulations and record the results on their WS. Special care should be taken when comparing the oscillation of the particles in the 1st and the last column of the material.<br><br>At the end, in 3.2,3 the students are asked to draw conclusions on the process of heat conduction in metals. | The students observe that the phenomenon of heat conduction in the metallic rod proceeds much faster than in the ceramic one.<br><br>The teacher asks students to answer the questions on the WS and insists mainly to the comparison of the oscillation of the particles in the 1st and the last column of the material as well as the comparison of the motion of electrons in the 1st and the last column, emphasizing the difference between “oscillation” of the particles and “motion” of the electrons.<br><br>The teacher also discusses multiple representations of conduction on the screen as well prompts the students to make links between the micro, the macro and the graph<br><br>Finally, in 3.2.3 the teacher guides the discussion with the students about how heat conduction happens in metals and prompts them to base their replies on the simulated model. |

## 3.3. CONCLUSIONS AND COMPARISON OF HEAT CONDUCTION IN CERAMICS AND METALS

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students proceed to “Step B” which deals with the comparison of heat conduction in a ceramic material and a metal.<br><br>Afterwards the students write down their observations in the table.<br><br>The students participate in the whole classroom discussion. | The students observe the phenomenon of the simultaneous heating of a ceramic and a metallic rod and complete the Table on their WS.<br><br>Before completing the Table, the teacher should focus students’ attention to the two physical variables involved: the time needed for the materials to warm up and the temperatures at the end of the rods (initial, final and their difference). An example of the completed Table follows.<br><br>The students observe the simulations and the teacher coordinates the discussion on the conclusion that can be drawn about which is the most conductive material, from the perspectives of both time and the temperature differences. |

| | CERAMIC MATERIAL | METAL |
|---|---|---|
| Time needed for heat transfer from the left end of the rod to the right end | 41 sec | 7 sec |
| Final temperature at the left end of the rod | 185 ˚C | 195 ˚C |
| Final temperature at the right end of the rod | 100˚C | 160˚C |
| Temperature difference between the two ends of the rod | 85 ˚C | 35˚C |
| I conclude that the material is: | insulating | conductive |

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students compare the results as tabulated in the Table and get involved in a discussion around the questions 5.0.1 of the WS. | Afterwards, in 5.0.1 the teacher prompts the students to make some links between simulated results and the demonstration experiment<br>Important details that should be discussed: |
| Question 5.0.2 is also answered by the students about the role of simulations. | - The temperature difference at the ends of each rod. The phenomenon is actually a case of heat diffused into the environment. However, if students themselves do not bring up the role of the environment in the phenomenon, the teacher may skip the issue at this phase of the teaching. |
| The students are asked to reflect and write down how simulations helped them to understand the subject matter, i.e. the role simulations played in their learning of the new knowledge. | - The process of heat conduction in ceramic materials and in metals. Students should explicitly state the cause of the differences in the process of thermal conduction: propagation / transfer of the oscillation of particles in ceramics, and in addition propagation / transfer of the motion of electrons in metals. |

## 3.4. ASSIGNMENTS (AND SOME THEORY) AND EXTENDED ACTIVITIES

The teacher hands out to the students one text of theory either here or at the end of the whole sequence. The text concerns the nature and use of models and is written as a self reading material. The students are asked to read the text and fulfil the metacognitive questions 6.4 about models afterwards in order to think of and appreciate what scientific models are about.

# UNIT 4: THERMAL CONDUCTIVITY OF METALS

## 1.0. OBJECTIVES OF THE UNIT:

- The students will get familiar with experimental techniques in order to detect the effects of thermal conductivity.
- The students will plan and discuss an experimental investigation to investigate thermal conductivity of metallic rods.
- The students will work in groups to carry out a "hands on" investigation in order to rank metallic rods according to their thermal conductivity.
- The students will draw on the use of conductors in house and everyday situations and will familiarise with web searching about materials.
- The students will reflect upon experimental design and specifically on technological factors affecting choice of materials.

## 1.1. DURATION OF THE UNIT:

1 teaching hour

## 2.0. CLASS ORGANIZATION:

Demonstration experiment is performed in front of whole classroom; experimentation is carried out by students working in teams.

## 2.1. MATERIALS:

1 set of 4 metallic rods (aluminium, iron, copper and bronze), thermal paper, 4 small candles (tea lights), 1 magnet, 1 ruler.

In addition:

**For the teacher:** heat resistant gloves (to handle hot rods)

**For the students:** 1 book (up to 2 cm thick), erasers and pencil sharpeners (to stabilize the rods)

**Teaching notes:**

## 3.0. ATTENDING AND DISCUSSING A DEMONSTRATION EXPERIMENT

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students observe the demonstration.<br><br>The students discuss about the experimental technique. | The teacher describes the experiment in detail to the students before performing the demonstration. During and after the demonstration the teacher prompts the students to discuss what happens and think of an interpretation in terms of heat conduction. The discussion should also focus on the experimental technique e.g.<br>• what is the use of the thermal paper?<br>• what evidence does it provide? |
| The students link experimental results with personal experiences for feeling heat conduction. | Also links with everyday phenomena are pursued such as a spoon inserted in hot water. |

## 3.1. A FIRST ATTEMPT TO DESIGN AN INVESTIGATION

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| Having experienced the demonstration and the ensuing discussion the students are involved in group discussion in task 2.1 about planning an experimental investigation. | During 2.1 the teacher asks the students to turn to the worksheet and work in their teams in order to plan and suggest an experimental procedure for to ranking 4 metallic rods according to their thermal conductivity.<br>Then the teacher discusses the proposals by the teams of the students and tries to immerse them in specifying:<br>• what is the question,<br>• what are the materials they should choose,<br>• what steps they should follow and pose some argument about and<br>• what the quantity should they measure . |

## 3.2. MEASURING METALLIC CONDUCTIVITY BY HANDS ON EXPERIMENT

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students work in teams of 3-5.<br>The students first have to identify the rods, by using the hints contained in the table of the WS regarding their properties.<br><br>FIG. 4.1<br>The students place the thermal paper on the book and they place the 5 rods parallel to each other. Then they have to stabilize the rods by using erasers or pencil harpeners. The rods should protrude beyond the book by about 3 cm . | The teacher hands out a piece of thermal paper to each group. Only one side of the thermal paper is thermochromic and thus suitable for the experiment. The sided needed is the one that leaves a visible mark when scratcher with a fingernail. Thermal papers sheets handed by the teacher should have such a mark at a corner, so that students easily recognize the correct side of the paper to be used. |

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students make a note on the thermal paper marking the position and the material of each rod. Then they place under the free end of each rod a candle WITHOUT lighting it up. | The teacher hands each group 4 candles (quenched). The candles should contain the same amount of wax, so when lit, their flames touch the rods in a similar manner. The teacher instructs groups to rehearse the exact position of the candles under the rods after they light them up. |
| The students position the candles under each rod SIMULTANEOUSLY. Students take special care the ends of all rods are WELL COVERED by the flames of the respective candles. | Then, the teacher lights up the candles and asks students to position them under each rod SIMULTANEOUSLY, taking special care the ends of all rods are WELL COVERED by the flames of the respective candles. |
| Students quench the candles when asked by the teacher. | The candles should be burning for about 10 minutes. |
| **WARNING: Students should NOT touch the rods using bare hands, especially the heated end!** | After about 10 min, the teacher removes the rods from the thermal paper, using heat resistant gloves. |
| The students observe the traces left on the thermal paper and record their observations on the WS. | The teacher coordinates students' experimental activity and takes care so that the students are carrying out the experiment, taking measurements and deducing relations. He asks the students to compare the traces left by the metallic rods and rank them in increasing length order: |
| The students measure and compare the length of the traces and then fill up the table in which they relate the material as an independent variable with direct measurement of the length of its trace as a dependent variable and hence with its thermal conductivity. | The longest trace is left by the copper rod and the next longer one by the aluminium rod. Their traces are quite long. Then follows the medium length trace by the bronze rod and finally the iron trace.<br>ATTENTION!<br>(We note here the thermal conductivity coefficients (κ, in W/m*K):<br>Copper: 398<br>Aluminium: 247<br>Bronze (70% Cu : 30% Zn): 120<br>Iron: 80 |

### 3.3. CONCLUSION AND DISCUSSION

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students work within their groups to decide which metallic rod is more conductive on the basis of experimental evidence. | The teacher prompts the students to construct evidence based conclusions.<br>He reminds the students that bronze is an alloy and helps them that this is neither better nor worse conductor than pure metals. |
| Afterwards the students proceed to fill up the table in section 4.0 working within their groups. | This is an important activity with respect to experimental methodology aiming at helping the students to identify and realise which quantities might have an effect, which did and which did not. Also to construct causal relations between changes in independent variables and dependent variables. The activity should be carried out initially in groups followed by whole classroom discussion. However it is up to the teacher to decide the structure of this activity. |

### 3.3. EXTENDED ACTIVITIES

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students may handle questions 5.1 and 5.2 either orally in the classroom or in writing at home. | As in the previous units these are optional metacognitive tasks aiming at facilitating students to reflect on what they did and what are possible difference with their initial experimental design. |
| In 5.3 the students work individually and search in the web on one specific site to find answers and try to identify differences between the laboratory based problem and a real technological one. | It is suggested to the teacher that the students carry out at home or in classroom the next activity 5.3 in which they are engaged in a modern technological problem appealing to them. |

# UNIT 5: THERMAL CONDUCTIVITY OF CERAMICS – PART A

## 1.0. OBJECTIVES OF THE UNIT:

- The students will investigate the relation between density and conductivity of ceramic materials.
- The students will carry out an investigation on a simulated lab.
- The students will rank materials according to their conductivity.
- The students will design an experimental procedure to investigate the relationship between density and conductivity in ceramic materials.

## 1.1. DURATION OF THE UNIT:

1 teaching hour

## 2.0. CLASS ORGANIZATION:

Students collaborate in groups of two in front of each computer.

## 2.1. MATERIALS:

Virtual Experiments on the computer:
Virtual Experiments: Cooling Lab 3

**Teaching notes:**

## 3.0. ELICITATING STUDENTS' VIEWS

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students are asked to answer the following question:<br>In the first lab, we found out that the temperature of hot water was dropping down faster in the glass cup than in the plastic one. Thus, we concluded that glass CONDUCTS heat easier than plastic.<br>What do you think happens at the microscopic level? | The students in a previous unit saw that the temperature of the hot water in the glass cup was falling sooner than in the plastic one.<br>This task aims at prompting students to do some thinking and discuss in terms of the microscopic model. Although both glass and plastic are insulators the question arises why their conductivity is different. |

## 3.1. THE VIRTUAL EXPERIMENT

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students run the virtual lab "Virtual<br>Experiment", choose "Cooling" and then "Lab3".<br>The students are to compare the cooling of two equal volume quantities of water (50 ml) having equal temperatures (80 °C) but contained in two different vessels, a glass one and a perspex one.<br>Before carrying out the activity, the students have to answer the prediction question regarding the final temperature of the water in each vessel (the glass one and the perspex one), if the vessels are allowed to interact with the water of the external vessel. | The students run the virtual lab, which in fact simulates an experiment they carried out in the previous unit using different materials (instead of glass-plastic they use glass-perspex). Here they will be able to change easily parameters in the environment of the virtual lab as well as link the evolution of the phenomenon with the corresponding real time graphs.<br>The students should read carefully the instructions of the WS, note the initial data in Table 1, reply to the prediction question and then carry out the experiment. |

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students carry out the experiment, following the instructions of the WS, take notes, discuss and collaborate within the teams.<br><br>The students observe the thermometer and the related real time graph. | The students carry out the experiment and while the phenomenon is evolving, the teacher prompts them to observe that:<br>- the hot water in the vessel is cooling down and the temperature graph represents in real time the falling of temperature in a falling curve.<br>- the symbol for heat 'Q' fades out. In order to make students fully aware of the last change in the colour of 'Q', they are asked to stop the procedure at the 10th minute and discuss among their group the reason why 'Q' fades out.<br>The two above observations in fact refer to the same phenomenon: with the passing of time, the rate of cooling is reduced; therefore, the more the slope of the curve is becoming more horizontal. This fact must be discussed with the teacher since it is hard to be identified by students, who have not extended experience with graphs. Besides the teacher draws attention to the students that gradually the 'Q' symbol fades away (an indication more clearly perceived by students). |
| The students are asked to where the curve will eventually converge, that is, toward which temperature value (which line on the y-axis) the line will converge at the end of the phenomenon. | The students easily expect the convergence towards 50 $^{o}$C, which is the mean value of the initial temperatures of the equal quantities of water. Apart from this 'theoretical' argument, the same seems to be suggested by the graph. |
| Finally, the students are asked to **note**, for the same material, the time required to reach thermal equilibrium between the two quantities of water as well as their final temperatures. | Here, the expected 'theoretical' final temperature value, as well as the time required for thermal equilibrium, is also shown in graph. |
| The students repeat the same procedure for Perspex and fill in Table 2 with their observations from the simulated experiment. | The second run of the experiment is carried out by the students faster, since they are now familiarized with the virtual lab interface. |

## 4.0. CONCLUSION

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| After filling up the table 2, the students are asked to write down and argue which material is more thermally insulating, glass or Perspex. | The teacher helps in the announcement of students' experimental results and coordinates the final discussion in order to help them construct their conclusions. |

## 5.0. FURTHER DEVELOPMENT, DESIGN OF A NEW INVESTIGATION

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students work to find out the relation density - conductivity by drawing on the results of the experiment. | In the following task 5.0 the teacher introduces a new quantity, namely the density of the materials and prompts the students to relate density with conductivity in ceramics. A table with all the quantities, material, temperature, density could be helpful if used as tool for guiding students.<br>Then he sets out the question. Can the above conclusion be generalized? What can we do to verify this hypothesis? |
| The students discuss within their teams the demands of task 5.0 and propose an experimental procedure that would validate or reject their replies by drawing on their previous knowledge about carrying out experimental investigations which has been constructed during the previous units through either real or simulated experiments. | Students are prompted to design an investigation in order to accept or reject their answers. In this case the question is given but the resources and the ways to answer are not.<br>The answer to the task 2.0. of this unit may be discussed with the students at this point. The aim is to help the students to link experimental data with the microscopic model. |

### 5.1. FURTHER APPLICATIONS DISCUSSED IN THE CLASSROOM

Afterwards the teacher refers to a number of ceramics like plastic, polymers etc and discusses their use for insulating purposes, drawing examples from house and personal experience. He also discusses the implications for heat loss and energy saving at the house.

Discussion on why the astronauts don't get burned even though the temperature outside the shuttle rises to hundreds of degrees while returning back to earth. **Ceramic plates** insulate the internal of the ship.

FIG. 5A.1

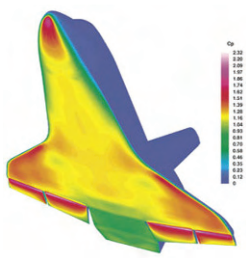


FIG. 5A.2

# UNIT 5: THERMAL CONDUCTIVITY OF CERAMICS – PART B

## 1.0. OBJECTIVES OF THE UNIT:

- The students will argue about experimental procedures to verify or reject a hypothesis
- The students will investigate the relation between density and conductivity of ceramic materials.
- The students will carry out an investigation on a simulated lab.
- The students will rank materials according to their conductivity.
- The students will choose the appropriate insulating material for a specific purpose.
- The students will draw on the use of insulators in house and everyday situations.

## 1.1. DURATION OF THE UNIT:

1 teaching hour

## 2.0. CLASS ORGANIZATION:

Students collaborate in groups of two for each computer

## 2.1. MATERIALS:

Virtual Experiments on the computer:
Virtual Experiments: Cooling Lab 4

**Teaching notes:**

## 3.0. INTRODUCTORY DISCUSSION

The teacher should have grouped in advance students' proposals on the experiments they suggested in the previous lesson. In the beginning of the lesson he reads aloud some representative examples and asks the students to provide arguments for their proposals or question other students' proposals. Then he/she coordinates a discussion among them (for about 10 minutes). In case some students involve metals in their proposals, the teacher challenges them whether their choice is appropriate. It is expected that some students will mention that the process of thermal conduction in metals is different from that for ceramic materials.

Afterwards, the teacher asks the students to express their opinion in class, as to whether they changed their initial views regarding the experimental procedure they suggested after participating in this discussion. The teacher gradually guides the students to think of proper methodology in order to investigate and find the relation density/conductivity in ceramics as well as to compare it with the approach they envisioned. The students realize that the variable is the material of one vessel and what other factors must be kept constant in order to have a valid investigation.

Then in task 2.0 the students proceed to follow instructions in the work sheet.

### 3.1. VIRTUAL EXPERIMENT

| STUDENT ACTIVITIES | TEACHER COMMENTS |
| --- | --- |
| The students run the virtual environment "Virtual Experiments", "Cooling and then "Lab4".<br><br>The students will compare the cooling of two equal volume quantities of water (50 ml) having the same temperature (80 °C), but contained in different vessels, a glass one and a bakelite one. | The students run the virtual lab they are about to work on. In essence, it's the same experiment they carried out in the previous unit, but now they use different materials (instead of glass-Perspex they use glass-Bakelite).<br><br>The students should read carefully the initial data on Table 3 and carry out the virtual experiment. |
| The students carry out the virtual experiment and complete Table 4. | The students carry out the virtual experiment and while the phenomenon is evolving, they observe that:<br><br>- hot water in the vessel is cooling down and its temperature follows a falling curve.<br>- the symbol for heat 'Q' fades out.<br><br>Students record the final temperature and the time required to reach thermal equilibrium.<br><br>The experiment is carried out by students fast, since they are already familiar with the virtual lab interface. |

### 4.0. CONCLUSIONS

| STUDENT ACTIVITIES | TEACHER COMMENTS |
| --- | --- |
| The students are asked to discuss whether glass or bakelite is more thermally conductive.<br><br>Then the students take into account the different densities of the materials used (glass, perspex and bakelite), generalize the result, and construct relation between the density and the respective thermal conductivity of materials. | The teacher assists the groups in the expression of their experimental results and coordinates the discussion in order to help them construct conclusions and reflect on their predictions. |

### 4.1. DISCUSSION ON THE EXPERIMENTAL METHODOLOGY

| STUDENT ACTIVITIES | TEACHER COMMENTS |
| --- | --- |
| The students discuss and fill up the table 4.0. | The teacher prompts and guides the students to fulfil the table in 4.0. Depending on the class this may take place in teams and then in whole classroom discussion or carried out by whole class discussion. The table acts as a tool to facilitate students reflection on their proposals as well as on the structure of the simulated experiment. |

## 5.0. THE CASE OF METALS

The teacher asks the students to reconsider the rod comparison experiment and the experimental results and try to find a relation with the density of each material in order to show to them that density is not a valid criterion for estimating conductivity in metals. This task is demanding but helps the students to identify another difference between metals and ceramics. It is suggested that this task is carried out in whole classroom under teachers' guidance.

## 5.1. CLASSROOM DISCUSSION

The teacher poses a problem and asks the students to design an experimental activity to find out the solution. The problem has to do with the correlation of conductivity with temperature.

## 6.0. EXTENDED ACTIVITIES

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students are prompted to search in Wikipedia to read about polymers and specifically plastics.<br>The students are asked to name 3 examples of the use of plastics.<br>Then they study the Table of Recyclable Polymer Materials. | The Table of Recyclable Polymer Materials is a good opportunity for the students to apply the recently acquired knowledge. In the Table, in addition to the inter¬national logo for recycling, are shown the name of the polymers, their density and their main use in everyday life. |
| By observing the densities of plastic materials in the Table the students rank the materials in decreasing thermal conductivity order. | The students rank the materials in decreasing thermal conductivity order, based on their density shown in the Table, as follows:<br>PVC, PET, PS, HDPE, LDPE and PP. |
| The students choose appropriate materials from the Table, according to their use, and compare their views with their peer groups. | Based on the density data, the students choose PP as the most thermally isolative material (since it has the lower density) and PET as the most thermally conductive. In the ranking it is shown that PVC has the highest density but it is NOT used for food packaging. Thus the students are expected to choose the material with the next higher density, i.e. PET.<br>In this way, the students are given the opportunity to reflect and discuss an additional criterion for the choice of appropriate materials for everyday use. They realize that in addition to density/thermal conductivity considerations (physical criterion), they should also consider health issues (toxicity of the materials), which is a technological criterion. The teacher coordinates the discussion to highlight these classes of criteria. |

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students make drawings of how they imagine at a microscopic level the structure of the most thermally conductive plastic material, as well the least thermally conductive one.<br><br>They present and discuss in class about the features of their drawings. | The teacher supervises the students as they make drawings of how they imagine the structure of the two materials and coordinates a discussion in order to reveal the characteristics of their representations. If feasible the students produce posters with revised drawings.<br><br>The students usually draw the higher density material having denser rows and columns of particles. |

Tasks 7.1, 2, 3 are given to the students as means to involve them in applying their knowledge in everyday yet usually misunderstood situations.

# UNIT 6: FACTORS THAT AFFECT HEAT FLOW - THICKNESS

## 1.0. OBJECTIVES OF THE UNIT:

- The students will plan an investigation and carry out an investigation in a virtual lab on how the size of the thickness of walls of a vessel affects thermal conduction in cooling situations.
- The students will use experimental evidence to decide on an everyday problem.
- The students will discuss how the size of a surface affects conduction and the experimental handling of several factors.

## 1.1. DURATION OF THE UNIT:

1 teaching hour

## 2.0. CLASS ORGANIZATION:

Students collaborate in teams of two on each computer

## 2.1. MATERIALS:

Virtual Lab “Thermo Lab”.

**Teaching notes:**

## 3.0. ONE DAY AT HOME

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students encounter the following everyday problem:<br><br>“Your mother left on the stove the milk she was preparing for your breakfast, a little more time than usual. In order to cool it down quickly, she poured it from the initial glass which had thin walls, into a same size glass having thicker walls. She believed that this way, the milk should cool down faster.<br><br>Do you agree or disagree with her action? Why?” | This task investigates students’ views on an everyday situation-problem. The students have to draw on their experiences referred to the “thickness” of objects as related to thermal conduction through them, predict what will happens and decide on mothers’ action. |

## 3.1. THINKING ABOUT THE PROBLEM

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| Afterwards, the question is restated as an open problem to be approached by an appropriate plan. The students are asked to plan and discuss within their teams ways through which they may verify experimentally or reject their views. | The teacher encourages the students to suggest their plans avoiding to provide them with guidance as in previous units. He then announces selected students’ proposals and encourages them to express suitable arguments to support them so that the students are engaged in an investigative discussion.<br><br>It is expected that discussion will lead gradually to refinement of students’ plans and to a productive method for collecting valid evidence. |

## 4.0. VIRTUAL COOLING EXPERIMENT: THE SCIENTIFIC APPROACH

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students run the Virtual Experiment SEP.<br>The students follow the instructions in the WS | This virtual experiment refers to cooling. The experimental procedure is familiar to the students from previous units. (Additional activities before the implementation of the TLS in Part C). |
| The students construct the experimental set up, with the appropriate values, for carrying out this virtual experiment. Then they make observations, keep notes and fill up the Table and write down answers to the questions of the WS. | The students have already experiences with handling virtual vessels and arranging properties in the environment SEP.<br>The teacher guides the students to read carefully the instructions of the WS.<br>It is important that the students are guided to fill up values of T and t in the table so that they can relate these two variables. |

## 4.1. CONCLUSION

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students discuss in their teams, write down individually and draw conclusions regarding the relation between wall thickness and time for cooling. | The teacher coordinates class discussion so that the students:<br>- express the conclusion that thickness affects conduction (e.g. the more the thickness of a vessel, the slower is heat conducted to the environment. |
| The students are asked to reflect on the initial problem and their predictions and decided to accept or reject them. Finally they decide that the mother was wrong on the basis of scientific evidence. | The teacher, after the students have reflected on their decision, discusses the action of the mother: that mother did a wrong choice, her action would make the drink cool down later!<br>Finally, the teacher discuss with the students what activities they did in order to solve the problem, why they choose such actions and about the value of scientific methodology in providing valid answers to every day situations. |

## 5.0. FACTORS AFFECTING CONDUCTION

| STUDENT ACTIVITIES | TEACHER COMMENTS |
|---|---|
| The students work in their teams to provide answers to task 5.1. Then they announce their results so that all the class becomes aware of them.<br><br>Then they proceed to task 5.2 and Task 5.3 where they are prompted to reflect and discuss about the factors that affect conduction and if it is possible to control **all the above factors** simultaneously with **only one experiment** | Groups studied experimentally thickness as a factor affecting conduction. Now they are faced with an everyday problem in which area is another factor affecting conduction. The teacher coordinates this discussion among the groups, so that all students get a global idea of all factors affecting conduction. During the discussion, in case the students don't mention it, the teacher should remind them that the material itself is a factor affecting conduction.<br><br>The teacher coordinates this important discussion about treating separate factors and why it is necessary to study one factor (variable) at a time in order to find causal relations. He also prompts the students to study about experimental method at the initial pages of their textbook.<br><br>Beyond the cups which are mentioned in the initial problems, the students are asked to identify situations in which surface area and thickness affect conduction. The teacher, for example, discusses such cases in the house drawing on thickness as one factor affecting heat flow through the walls and consequently energy loss or saving. |

## 6.0. SITUATIONS FOR ADDITIONAL DISCUSSION

In which case conduction is faster?

How may we provide experimental evidence and provide a data supported reply?

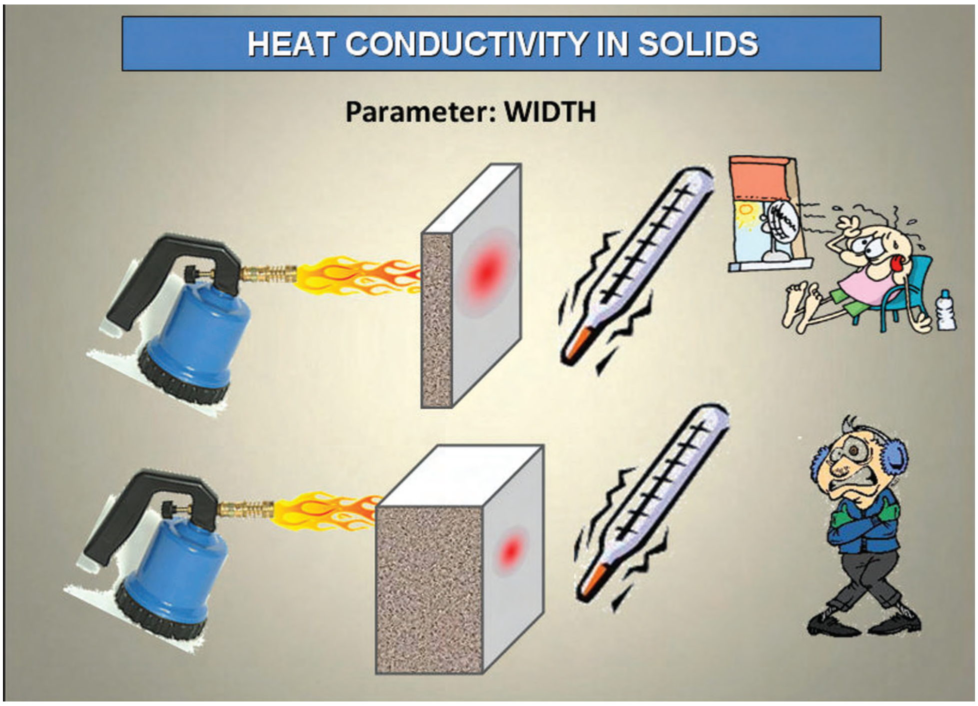



FIG. 6.1

# UNIT 7: THERMAL CONDUCTIVITY OF SOLID MATERIALS

## 1.0. OBJECTIVES OF THE UNIT:

- The students will reflect upon concepts and models they have been taught.
- The students will reflect upon factors affecting conduction.
- The students will apply their knowledge in several everyday situations and consider energy saving issues in a house.
- The students will familiarize with different model representations in the web.
- The students will work out how everyday (insulating, conducting) technological artifacts around us are made of.

## 1.1. DURATION OF THE UNIT:

1 hour

## 2.0. CLASS ORGANIZATION:

Whole classroom work.

## 2.1. MATERIALS:

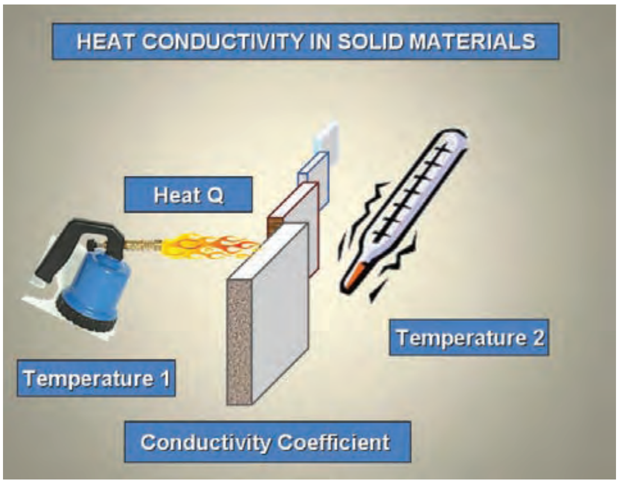
Powerpoint foils.

**FOIL 1**

Reflection on the concept of conduction.

The discussion is based on the question, why do we have conduction, when there is temperature difference between the two surfaces.

The importance of the kind of the material is noticed as well as of the temperature difference; the conductivity coefficient is discussed to some extend.

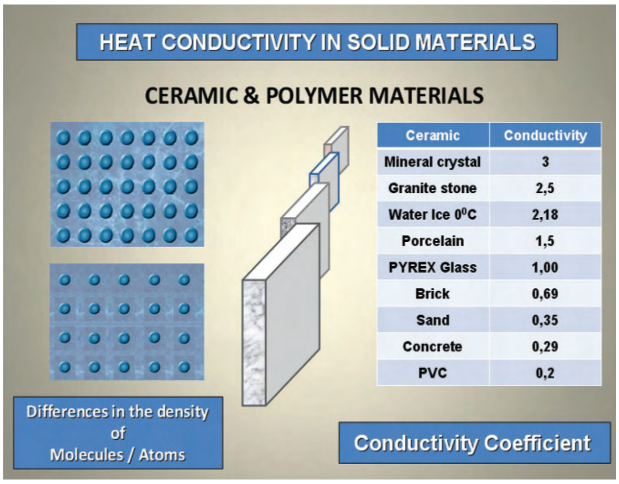


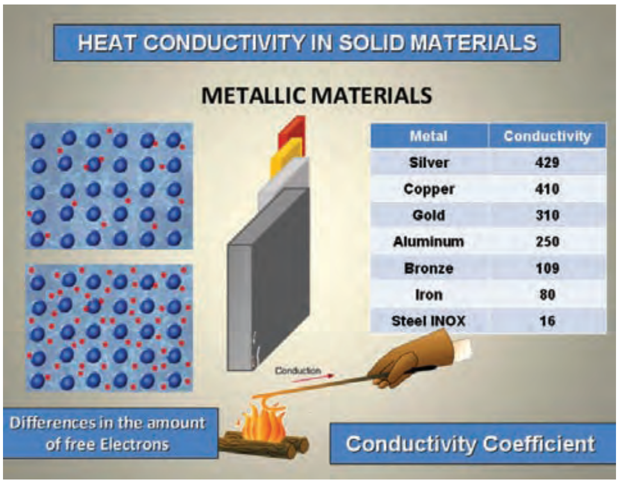

**FOIL 2**

Reference on the ceramic materials.

The microscopic process is presented. The students are asked to describe what do they observe and what have they already been taught.

ATTENTION The coefficient of several materials (without its units) is given just for comparison.



<table>
<tr>
<td>FOIL 3</td>
<td>Reference on the metallic materials.<br><br>The microscopic mechanism is shown. The students are asked to describe what do they observe and what have they already been taught. The students also discuss the difference between metals and ceramics.<br><br>Conductors and insulators as broad categories are also discussed and students are discussing several different familiar materials.<br><br>ATTENTION The coefficient of several materials (without its units) is given just for comparison.</td>
<td>
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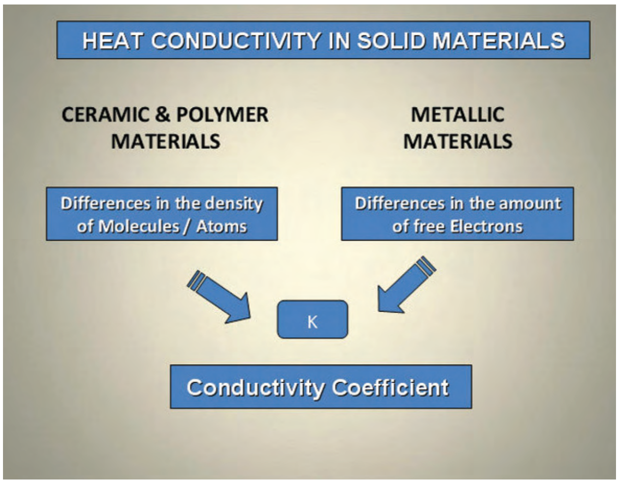
<tr>
<td>FOIL 4</td>
<td>Students are asked to reflect on the different kind of movement molecules and electrons are doing.<br><br>The coefficient of several materials (without its units) is given for comparison.</td>
<td>
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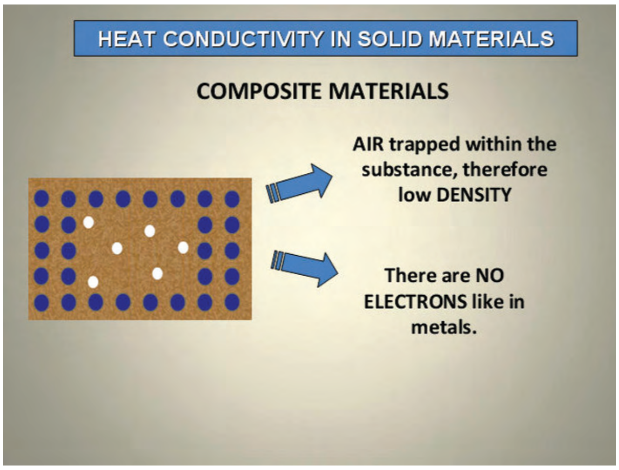
<tr>
<td>FOIL<br><br>5 & 6</td>
<td>New content, not previously presented.<br><br>Discussion and comparison with the other categories.<br><br>Notation on the importance of the cell within the materials.<br><br>The coefficient of several materials (without its units) is given for comparison.</td>
<td>

FOIL 5</td>
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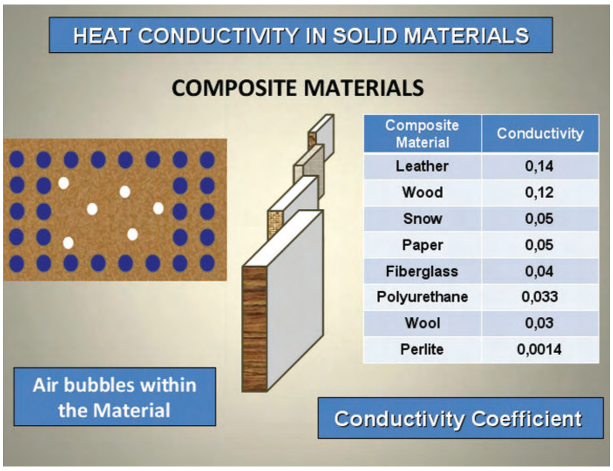


FOIL 6
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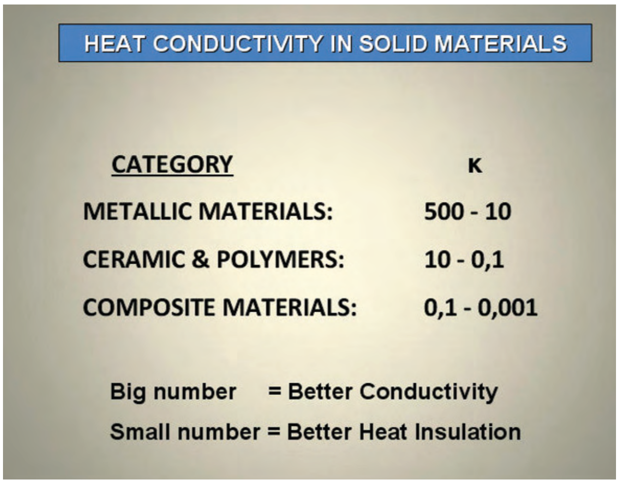
**FOIL 7**

</td>
<td>Comparison of the 3 categories regarding conductivity.</td>
<td>


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**FOIL 8**

</td>
<td>

Questioning about which case seems more conductive.

Reflection on how did they experimentally study the difference.

</td>
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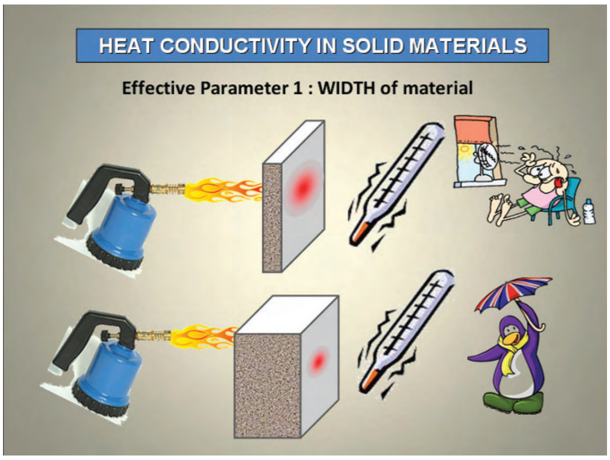

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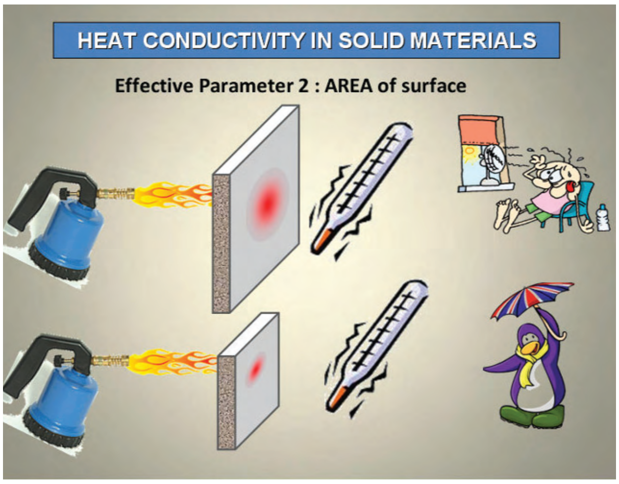
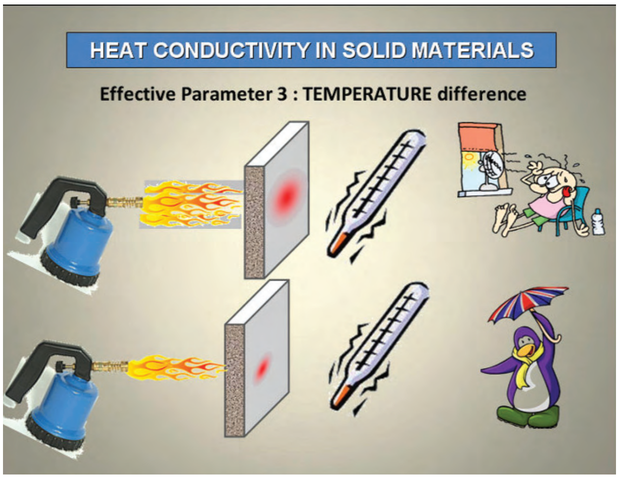
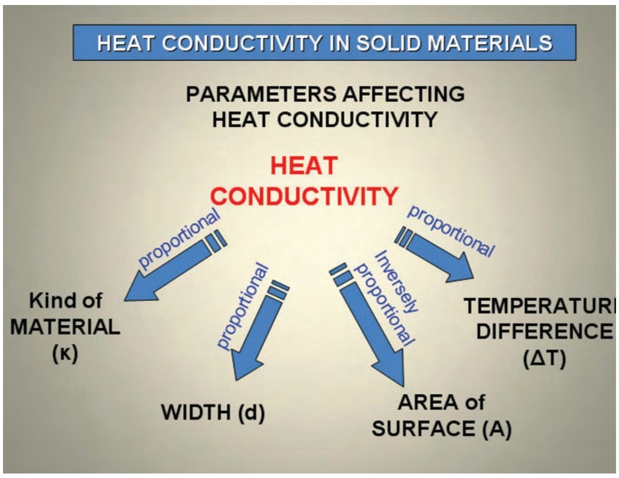
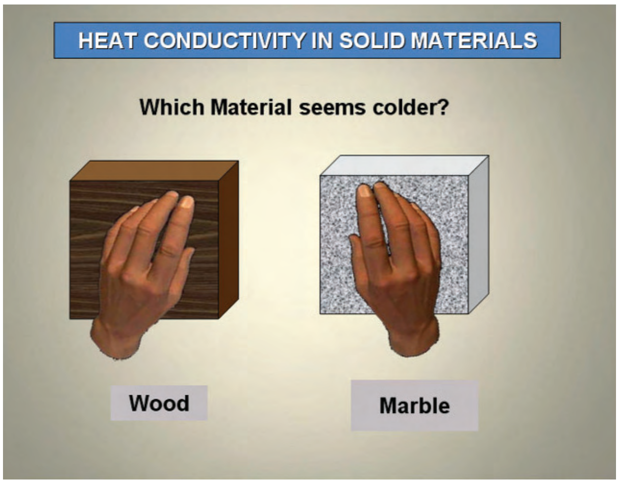
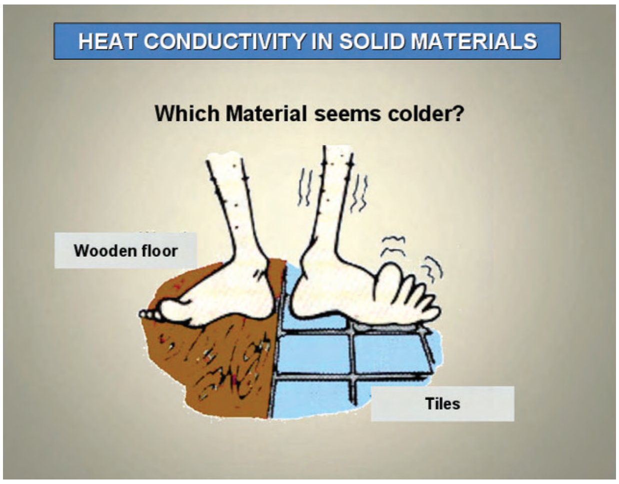
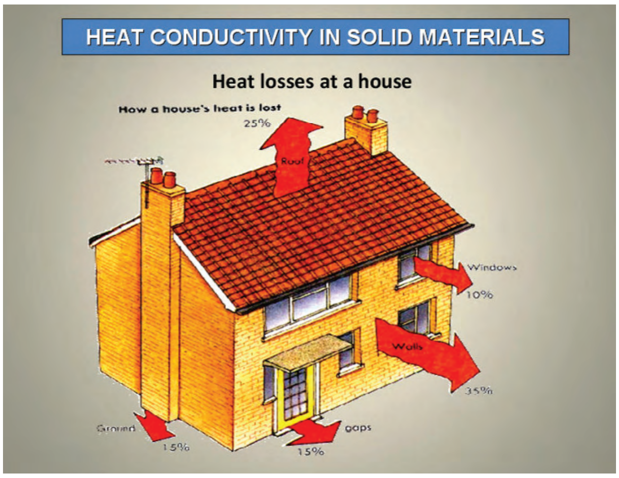
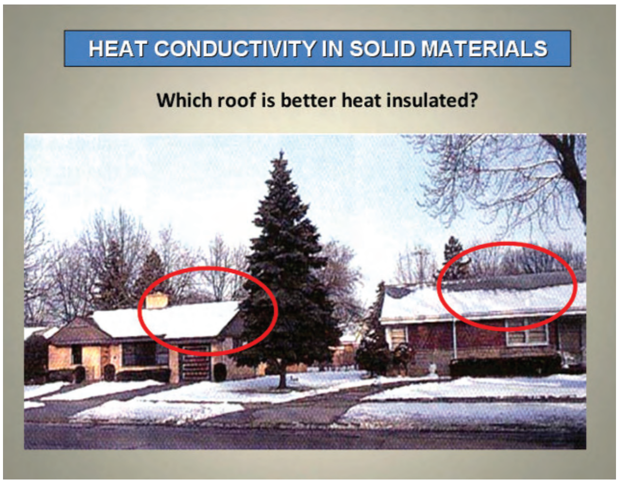
| | | |
|---|---|---|
| FOIL 9 | Reflection about which case seems more conductive.<br><br>Questioning on how did they study the difference. |  |
| FOIL 10 | Reflection on the role of the temperature difference in heat conductivity. |  |
| FOIL 11 | Discussion on all the parameters affecting heat conductivity. |  |

| | | |
|---|---|---|
| **FOIL**<br>**12 & 13** | Discussion on the consequences of heat conduction through every day's experiences, connected to thermal equilibrium.<br><br>There is reference on the feeling which is caused by touching several different materials which are in a room.<br><br>The students can touch with their hands, the desk, the chair, etc and the teacher can explain this feeling. | <br><br>FOIL 12<br><br><br><br>FOIL 13 |
| **FOIL**<br>**14** | Reflection about energy and heat conduction.<br><br>ATTENTION<br><br>At this picture, the heat loss is represented and a discussion follows concerning "energy save" issues. Questions are set out on how to reduce heat loss, an issue which is taken up in the next unit. | <br> |

| | | |
|---|---|---|
| **FOIL 15** | The students are asked to comment on the reasons why the snow at the two roofs of these houses melt in a different way and link this situation with what they studied in the laboratory. |  |

**Extended activities**
The students are asked to carry out individually or in teams within the classroom or at home tasks 2.1 and 2.2.

As in other cases in task 2.1 they will link their classroom study with resources in the internet. In this case they will find and compare different representations of the lattice and compare them with the taught ones in order to get insights that a model may appear in different representations.

In Task 2.2 the students search for the composition of familiar everyday insulating and conduction artifacts.

# UNIT 8: FOR A GREEN HOUSE! CHOICE OF MATERIALS FOR THERMAL INSULATION

## 1.0. OBJECTIVES OF THE UNIT:

- The students will familiarize with thermal photography
- The students will apply their taught knowledge and relate thermal insulation to energy savings in a house.
- The students will explore every day technological artifacts according to their use for insulating a house.
- The students will consider several factors affecting choices for the design of thermal insulation of a house.

## 1.1. DURATION OF THE UNIT:

1 hour

## 2.0. CLASS ORGANIZATION:

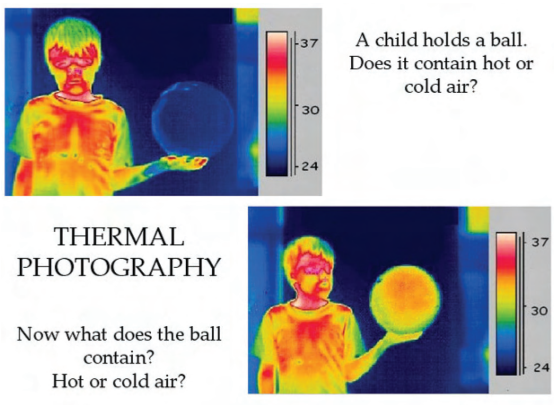
Whole classroom work and students collaboration in groups of two.

## 2.1. MATERIALS:

Powerpoint foils.

**Teaching notes:**

## 3.0. PART A

| TEACHER COMMENTS | |
|---|---|
| The teacher presents the first three slides of the presentation.<br>**1ST SLIDE:**<br>The teacher discusses the concept of a “green house”, i.e. a house where we try to minimize “thermal losses” in order to save more energy. He shows the slide of a house. | <br>FIG 8.1 |
| **2ND SLIDE:**<br>The students get familiar with thermal photography.<br>The teacher first assists students to understand the colour code and “read” heat flow in the first picture, and then asks them to do the same for the second picture.<br>The capture mentions that it is thermal photography | <br>FIG 8.2 |

**TEACHER COMMENTS**

### 3RD SLIDE:

The students apply the new knowledge to decode the picture in the third slide. As noted in the captures they are asked to identify, discuss and write down on their WS the differences between the parts of the house, namely the parts that are thermally isolated and the parts that are not.

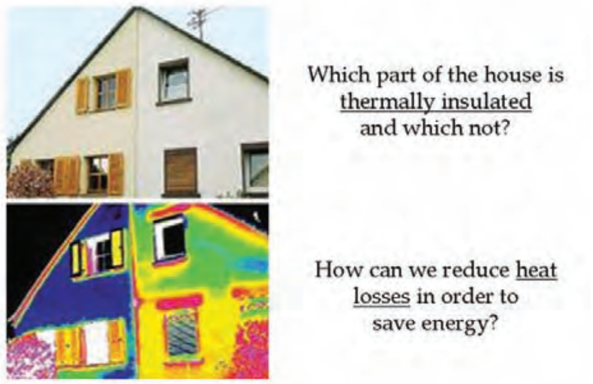



FIG 8.3

Then students are asked to suggest, in writing, ways to reduce heat losses and thus save energy.

## 3.1. PART B

The various groups in the class are divided into two broad teams: all the groups in the first team deal with the thermal insulation of windows and doors, while the second deals with the thermal insulation of the building's walls.

**Team 1**

The students are given data regarding the thermal conductivity of window panes:

type of window panes (single or double), thickness of a single glass pane, thickness of air gap between panes and thermal conductivity of each glass pane.

Students rank window types (materials) according to their thermal conductivity, discuss among groups, make decisions and write down which window type is preferred in order to achieve maximum energy savings.

***Table***

| Type of glass | κ (W/m²K) |
|---|---|
| single 4mm | 5.8 |
| single 6mm | 5.7 |
| single 10mm | 5.6 |
| single 12mm | 5.5 |
| double 4-12-4 | 2.9 |
| double 6-12-6 | 2.8 |
| double 10-12-6 | 2.7 |
| double 12-12-6 | 2.6 |

FIG 8.4

**Team 2**

The students are given data regarding the thermal conductivity of walls:

type of brick (plain or cored), thickness of intermediate insulation (between two brick walls) and the thermal conductivity of each case.

The students rank wall types (materials) according to their thermal conductivity, discuss among groups, make decisions and write down which wall type is preferred in order to achieve maximum energy savings.

| Thickness of outer wall | K-value with additional thermal insulation (in W/m$^2$.K) | | | | | |
|---|---|---|---|---|---|---|
| Additional insulation | Not insulated | 6 cm | 8 cm | 10 cm | 12 cm | 14 cm |
| 38 cm of plain brick | 1.45 | 0.45 | 0.37 | 0.31 | 0.27 | 0.24 |
| 38 cm of cored brick | 0.36 | 0.23 | 0.21 | 0.19 | 0.17 | 0.16 |

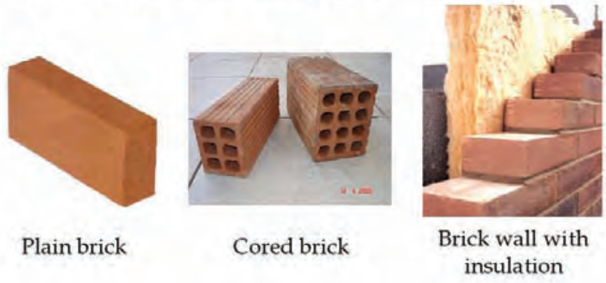



FIG 8.5

## 4.0. EXTENDED ACTIVITIES

The teacher coordinates a whole class discussion where the students from each team announce their decisions.

In case students' design decisions take into account only thermal aspects, the teacher guides them to bring forth additional factors that affect our choices when designing a house, such as cost, lighting (allowed into the house), health and security considerations, etc.

Finally the students are asked in task 4.2. to consider the role of insulation in house **BOTH** in the winter and the summer in terms of the knowledge they were taught in order to acquire a global view of insulation and its utility all through the year.

# C: DESCRIPTION OF EXTENSIVE ACTIVITIES

# C: DESCRIPTION OF EXTENSIVE ACTIVITIES

## 1. INTRODUCTION

In this Part suggested and additional activities are presented, which can be carried out before, during or after the implementation of the TLS.
Specifically in this Part can be found:

- Worksheets, which may be used before the implementation of the TLS aiming at students' familiarization with "ThermoLab" software (2.1).
- Worksheets, which may be used before the implementation of the TLS aiming at students' understanding of Thermal Equilibrium between quantities of water with varying masses or varying temperatures with "ThermoLab" (2.2 και 2.3).
- excerpts from Worksheets with activities aiming at:
  - the interpretation of thermal conductivity in alloys in a microscopic level (3.1),
  - the study of thermal conductivity with virtual experiments, during cooling at beakers with different thickness (3.2.1),
  - the study of thermal conductivity with virtual experiments, during heating at beakers with different thickness (3.2.2),
  - the study of thermal conductivity with virtual experiments, during cooling at beakers with different area of surface (3.3.1),
  - the study of thermal conductivity with virtual experiments, during heating at beakers with different area of surface (3.3.2) and
  - the study of thermal conductivity in composite materials as a project (4.1)

## 2. ADDITIONAL ACTIVITIES BEFORE THE IMPLEMENTATION OF THE TLS

### 2.1. FAMILIARIZATION WS WITH THE "THERMO LAB"

**Materials:**
Beaker 100 ml (ideal, it does not radiate), thermometer, source of heat (burner).Water in temperature 20°C.

**Create in the simulated laboratory the following set up:**

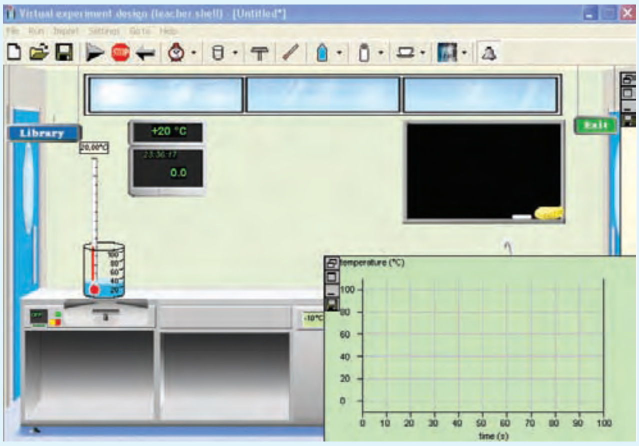



FIG.2.1.1

- The beaker holds 30g of water at 20°C.
- Activate the projection of graphic representation of temperature (axes: (0,100) sec, (0,100) °C).
- Temperature of ambient: 20 °C.
- Time acceleration: x 1

**Steps:**
Turn on the burner selecting low heat supply (it corresponds in 100 J/s).

Warm-up the water until it exceeds the 50°C.

Observe the rise in temperature of water from the thermometer and the corresponding line in the graphic representation.

**Make certain additions in the set-up:**

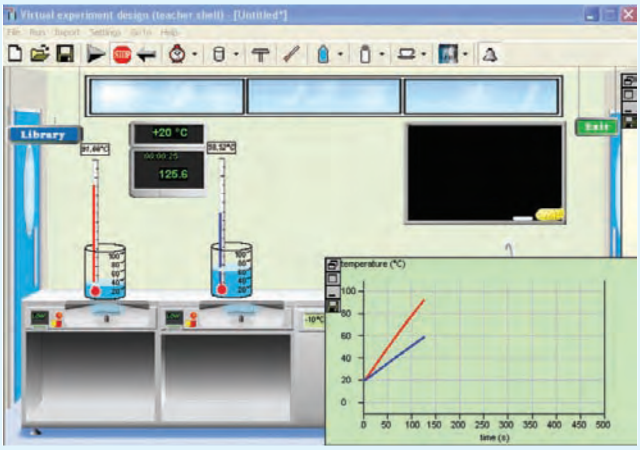



FIG.2.1.2

- Put a second 100ml beaker same with the previous one and another more thermometer.
- Fill the second beaker with 60g of water 20 °C.
- Also activate second burner, at low heat supply.
- Repeat the experiment.
- Observe once again the rise in temperature in both quantities of water from the thermometers and the two corresponding lines in the graphic representation.

**Fill-in the following table 1.** You can you find the values that are asked clicking with your mouse on the lines of the graphic representation. (It is not necessary you are absolutely precise. Round the values up into integers.

TABLE No1

| | TIME (t) REQUIRED | |
|---|---|---|
| TEMPERATURE | WATER 30 g | WATER 60 g |
| 20 °C | 0 s | |
| 30 °C | ..............s | ..............s |
| 40 °C | ..............s | ..............s |
| 50 °C | ..............s | ..............s |

- Now calculate the total heat that is provided by burner in water of 30g, in order to change its temperature from 20 °C to 50 °C, multiplying heat supply (100 J/s) on the time that was required for this change using data on table 1.Thus,

  $Q_1$=.................J

- Make the same calculation for water of 60 g:

  $Q_2$=.................J

- Now complete the following table (no3) with the values of heat that was provided by burner in two quantities of water for the rise in their temperature from the 20 °C in the 50 °C, as you previously calculated using the corresponding time needed.

TABLE No2

| | CHANGE IN TEMPERATURE | HEAT OFFERED FROM BURNER |
|---|---|---|
| Water 30 g | ..........°C | $Q_1$=...................J |
| Water 60 g | ..........°C | $Q_2$=...................J |

To which conclusion do you come? Was the same sum of heat needed for the same increase of temperature in both cases?

YES ☐ NO ☐

How exactly is the sum of heat that a body needs in order to increase its temperature depended on the amount (mass) of it?

.................................................................................................................................

The (bigger/smaller)................................ the mass of heated body it is, the (more/less)...........................amount of heat it needs.

Which relation do you see that this two sums have that is, the **mass** of body and required **heat** in this case?

They are ...........................................................................................................

What you observe for the bent of new line (for 60g)? Is it bigger or smaller than the bent of the initial line (for 30g)?

.................................................................................................................................

This means that for the same heat supply when the mass is bigger, the temperature of water is being altered:

FASTER? ☐ SLOWER? ☐

## 2.2. WS - THERMAL EQUILIBRIUM BETWEEN TWO EQUALS QUANTITIES OF WATER

**Materials:**
Beakers 100 ml (ideal), Beaker-thermos, Thermometers, Burners, Water.

**Create in the virtual laboratory the following set up:**

- The exterior beaker is thermos and contains 100 g of water at the temperature of 20 °C.
- The internal beaker contains 100 g of water at the temperature of 80 °C.
- Time acceleration: x 5
- Activate the projection of temperature vs.Time graph (axes: (0,300) sec, (0,100) °C).

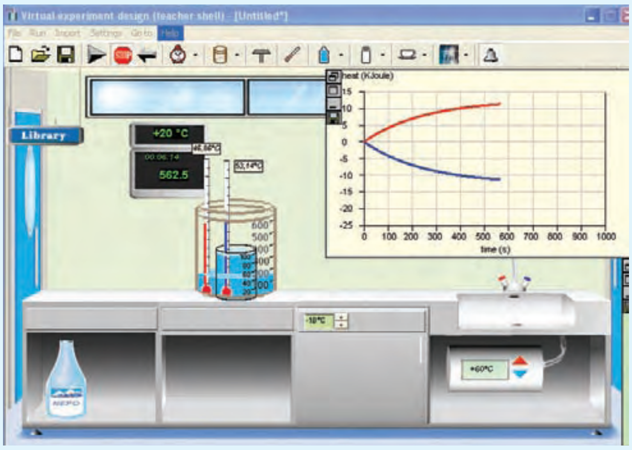


FIG.2.2

**Prediction**
If you let this closed system, that consists of two equal quantities of water interact, which do you believe the temperature in which it will reach thermal equilibrium will be?

100 °C ☐ 80 °C ☐ 50 °C ☐ 20 °C ☐

Why?

.................................................................................................................................................

Due to the fact that the system is closed, one of the two bodies offers and the other absorbs it. Which of the two do you believe that is the one that **offers** heat?

the hottest ☐ the coldest ☐

What do you think of the **algebraic sum of** heat quantities that are exchanged between the bodies? It'll be:

positive ☐ zero ☐ negative ☐

Checking your prediction

- Let the system of the two equal quantities of water interact (click on the key "**Run**").
- Observe the changes in the bodies' temperatures from the thermometers and the corresponding lines in the diagram of your graphic representations.
- Continue to watch the phenomenon, until you've reached Thermal Equilibrium State – roughly for 300 sec (click on the key "**Stop**").

**Fill-in the following table 1**
*(you will find the values that you need from the graphic representation "clicking" with the mouse on its line. Round-up to the first decimal digit)*

TABLE 1

| | TEMPERATURE | |
|---|---|---|
| **TIME** | **INTERNAL BEAKER (100 g OF WATER)** | **EXTERNAL BEAKER (100 g OF WATER)** |
| 0 sec | 80 °C | 20 °C |
| 50 sec | …………… °C | …………… °C |
| 100 sec | …………… °C | …………… °C |
| 150 sec | …………… °C | …………… °C |
| 200 sec | …………… °C | …………… °C |
| 250 sec | …………… °C | …………… °C |
| 300 sec | …………… °C | …………… °C |

At which temperature does the system reach thermal equilibrium State?

At…….. °C

Your prediction for the temperature in which the system would reach thermal equilibrium State was:

wrong ☐ right ☐

**Activate the heat vs. time graph (axes: (0,300) sec, (-50,50) KJ).**

**Fill-in the following table 2**
*(You will find the values that you need from the graphic representation "clicking" with the mouse on its line. Use signed numbers).*

TABLE 2

| | TOTAL AMOUNT OF HEAT (FROM/ TO) | |
|---|---|---|
| TIME | INTERNAL BEAKER (100 g OF WATER) | EXTERNAL BEAKER (100 g OF WATER) |
| 0 sec | .............. KJ | .............. KJ |
| 100 sec | .............. KJ | .............. KJ |
| 200 sec | .............. KJ | .............. KJ |
| 300 sec | .............. KJ | .............. KJ |

Your prediction for which of the two bodies of the system **was offering** the amount of heat was:

wrong ☐ right ☐

**From the data of table 2 calculate for each time instant the algebraic sum of the amounts of heat for the whole system of bodies and fill-in table 3**

TABLE 3

| TIME | TOTAL AMOUNT OF HEAT FOR THE SYSTEM |
|---|---|
| 0 sec | .............. KJ |
| 100 sec | .............. KJ |
| 200 sec | .............. KJ |
| 300 sec | .............. KJ |

Your prediction for who it is the **algebraic sum** of sums of heat that exchanges the bodies was:

wrong ☐ right ☐

## 2.3. WS - THERMAL EQUILIBRIUM BETWEEN TWO DIFFERENT QUANTITIES OF WATER

**Materials:**
Beakers 100 ml (ideal), Beaker-thermos, Thermometers, Burners, Water.

**Create in the virtual laboratory the following set up:**

- The exterior beaker is thermos and contains 200 g of water at the temperature of 20 °C.
- The internal beaker contains 100 g of water at the temperature of 80 °C.
- Time acceleration: x 5
- Activate the projection of temperature vs. time graph (axes: (0,300) sec, (0,100) °C).
- Activate the projection of heat vs. time graph (axes: (0,300) sec, (-50, 50) KJ).

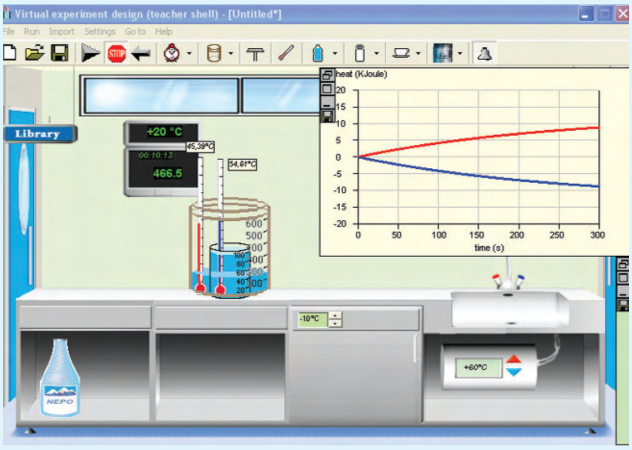



FIG. 2.3

**Prediction**
If you let this **closed** system consisting of **100 g of** water at the temperature of **80 °C** and 200 g **of** water at the temperature of 20°C, interact which do you believe that the temperature in which **it will reach Thermal equilibrium State** will be?

60 °C ☐ 50 °C ☐ 40 °C ☐

Why?

..............................................................................................................................................

What do you think of the algebraic **sum** of the amounts of heat exchanged between the bodies, now that their masses **are not equal**? It will be:

positive ☐ zero ☐ negative ☐

What you think of the amount of heat that **each body offered/received individually?** It must be: (in absolute value)

bigger than ☐ equal to ☐ less than ☐

that of the previous experiment (2.2)

What you believe for the time **that is required**, in order to reach Thermal Equilibrium State? It will be:

more ☐ equal ☐ less ☐

Than the time required in the previous experiment (2.2)

**Checking your prediction**

- Let the system of two different **quantities of water** interact (click on the key: "**Run**").
- Observe the change in bodies' temperature from the thermometers and the corresponding lines in the temperature vs. time and heat vs. time graphs
- Continue to watch the phenomenon, until you've reached Thermal Equilibrium State – roughly for 300sec (click on the key: "**Stop**").

**Fill-in the following table 1 (you will find the values that you need from the graphic representation "clicking" with the mouse on its line. Round-up to the first decimal digit).**

TABLE 1

| | TEMPERATURE | |
|---|---|---|
| TIME | INTERNAL BEAKER (100 g OF WATER) | EXTERNAL BEAKER (100 g OF WATER) |
| 0 sec | 80 °C | 20 °C |
| 50 sec | …………… °C | …………… °C |
| 100 sec | …………… °C | …………… °C |
| 150 sec | …………… °C | …………… °C |
| 200 sec | …………… °C | …………… °C |
| 250 sec | …………… °C | …………… °C |
| 300 sec | …………… °C | …………… °C |

At which temperature does the system of the bodies reach Thermal Equilibrium state?

At…….. °C

Your prediction for the temperature at which the system of the bodies would reach Thermal Equilibrium state was:

wrong ☐ right ☐

**Fill-in the following table 2**

*(You will find the values that you need from the graphic representation "clicking" with the mouse on its line. Use signed numbers).*

TABLE 2

| | TOTAL AMOUNT OF HEAT (FROM/ TO) | |
|---|---|---|
| TIME | INTERNAL BEAKER (100 g OF WATER) | EXTERNAL BEAKER (100 g OF WATER) |
| 0 sec | .............. KJ | .............. KJ |
| 100 sec | .............. KJ | .............. KJ |
| 200 sec | .............. KJ | .............. KJ |
| 300 sec | .............. KJ | .............. KJ |

Your prediction whether the amount of heat that each body offers/receives **individually** from the bodies of the system would be bigger than, equal to or less than that in the previous experiment was:

wrong ☐ right ☐

**From the data of table 2 calculate for each time instant the algebraic sum of the amounts of heat for the whole system of bodies and fill-in the table 3**

TABLE 3

| TIME | TOTAL AMOUNT OF HEAT FOR THE SYSTEM |
|---|---|
| 0 sec | .............. KJ |
| 100 sec | .............. KJ |
| 200 sec | .............. KJ |
| 300 sec | .............. KJ |

Your prediction whether the **algebraic sum** of the amounts of heat exchanged between the bodies would be positive zero or negative was:

wrong ☐ right ☐

Your prediction whether the **time needed**, to reach Thermal Equilibrium State,would be more, equal or less in comparison to the previous Lab was:

wrong ☐ right ☐

**What can you conclude from all your previous study?**
The temperature in which Thermal Equilibrium takes place is always:

bigger ☐ between ☐ smaller ☐

than the initial temperatures of the bodies which interact.

Whenever the interacting bodies are made of the **same material** and have **equal masses**, their Thermal Equilibrium **temperatures** are found precisely in the **means of their initial temperatures**, however if their **masses are not equal**, they reach Thermal Equilibrium at a temperature that **approaches more** that of the body which has:

a bigger mass ☐ a smaller mass ☐

In a closed system of two thermally interacting bodies the amount of heat offered by the:

hotter ☐ colder ☐

body is (in absolute price) equal to the amount received by the:

colder one ☐ hotter one ☐

In a **closed system** of thermally interacting bodies the algebraic sum of amounts of heat **exchanged** between them

positive ☐ zero ☐

The **bigger** the **mass** of the system's bodies the :

less ☐ more ☐

**is the amount of heat** exchanged between them.

The **bigger the mass** of the system's bodies the :

more ☐ less ☐

**time** is required, in order to reach Thermal Equilibrium State.

## 3. ADDITIONAL ACTIVITIES IN A VIRTUAL EXPERIMENT DURING THE TLS

### 3.1. ACTIVITY ON THE THERMAL CONDUCTIVITY IN ALLOYS

**Explanation at a microscopic level.**
We will study next, what happens in alloys. But what is an alloy? Alloys are homogenous mixtures where at least one component is a metal. Looking at the figure of the simulation, the little blue balls represent the metal and the tiny red balls represent the free electrons. The second material, with which the first metal forms an alloy, is symbolized by the orange balls. If this second material is also a metal, then it also offers free electrons. Otherwise only the electrons of the initial metal are remained.

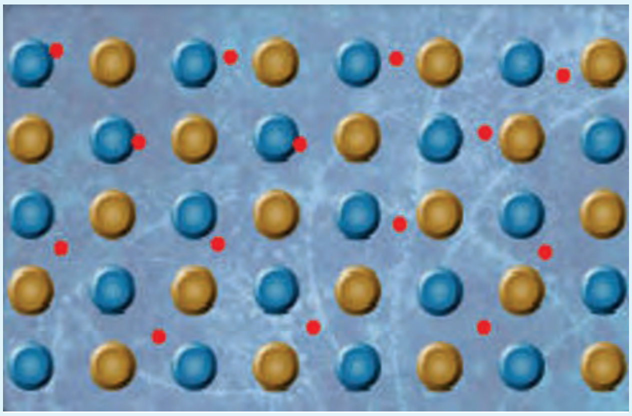


FIG.3.1

**Now open the «Lab5» at "Microscopic Models". At first, consider in brief on how heat is transferred in metals. Then, observe how heat will conduct in an alloy.**

**Now proceed to "Step A2" of the simulation, where a candle is lit to heat the alloy, and observe:**

**First, the vibration of the molecules.**
*What do you notice?*

..........

..........

..........

**Then, the vibration of the free electrons.**
*What do you notice?*

..........

..........

..........

**Finally, at "Step B", you have to compare the difference in heat transfer in the metal and in the alloy.**
*What do you notice?*

..........

..........

..........

## 3.2. ADDITIONAL ACTIVITIES REGARDING THERMAL CONDUCTIVITY AND THICKNESS

### 3.2.1. COOLING OF BEAKERS WITH DIFFERENT WALL THICKNESS

Open the virtual experiment “Cooling”, «Lab1». During this lab we are going to cool down a beaker filled with 50 ml of water with a temperature of 80 °C, after we put it in a beaker with a same quantity (50 ml) of water but with a temperature of 50 °C. You may choose between 2.5 mm or 5 mm thick walls for the internal beaker.

**Follow the next steps:**

1. Select the thickness of the walls of the internal beaker (type of beaker)
2. Place the small beaker (the one with hot water) into the big beaker (by clicking on the small beaker, this is automatically placed into the big one).
3. Place the thermometer into the small beaker (by clicking on the thermometer)
4. Press the button “Start” for running the experiment.

During the evolution of the virtual experiment, watch the formation of the curve on the graph.

*At which temperature is there going to be equilibrium between the quantities of the water in the internal and external beaker?*

........................................................................................................................

........................................................................................................................

........................................................................................................................

*After how much time is this equilibrium going to happen?*

........................................................................................................................

........................................................................................................................

........................................................................................................................

**For better accuracy of the above measurements, you can repeat the experiment and watch the time and temperature indications on the left side of the screen.**

**Now repeat the above steps at «Lab2». You may choose between 5 mm or 7.5 mm for the thickness of the walls of the internal beaker.**

**Fill up the next Table:**

| | THICK 2,5 mm | THICK 5 mm | THICK 7,5 mm |
|---|---|---|---|
| Initial water temperature at the small internal beaker | | | |
| Initial water temperature at the large external beaker | | | |
| Final water temperature at the small internal beaker | | | |
| Duration of final temperature restoration at the small internal beaker | | | |

**Notice the small heating arrow at the window of the wall.**
*What do you observe during the cooling process?*
*Why do you think this is happening?*

### 3.2.2. HEATING OF BEAKERS WITH DIFFERENT WALL THICKNESS

Now, open the virtual experiment “Heating”, «Lab1». During this virtual lab we are going to use a heater in order to heat 100 ml of water (initial temperature 20 ºC). We are going to follow the process till the temperature reaches 100 ºC. You may choose between 2.5 mm or 5 mm as thickness for the walls of the internal beaker.

**Follow the next steps:**

1. Select the thickness of the wall of the beaker.
2. Place the thermometer into the small beaker (by clicking on the thermometer).
3. Press the button “Start” for running the experiment.

During the evolution of the virtual experiment, watch the formation of the line on the graph.

*Which is the higher temperature that the water in the beaker will acquire?*

*After how much time will this happen?*

**For better accuracy of the above measurements, you can repeat the experiment and watch the time and temperature indications on the left side of the screen.**

**Now repeat the above steps by selecting «Lab2» where you may choose between 5 mm or 7.5 mm as thickness of the beaker..**

**Fill up the next Table:**

| | THICK 2,5 mm | THICK 5 mm | THICK 7,5 mm |
|---|---|---|---|
| Initial temperature of water in beaker | | | |
| Final temperature of water in beaker | | | |
| Time of final temperature restoration | | | |

***Notice the small heating arrow at the window of the wall.***
*What do you observe about that during the cooling process?*
*Why do you think this is happening?*

## 3.3. ADDITIONAL ACTIVITIES REGARDING THERMAL CONDUCTIVITY AND SURFACE

### 3.3.1. COOLING OF BEAKERS WITH DIFFERENT SURFACE

Open the virtual experiment «Surface», «Lab1». During this lab we are going to cool down a beaker filled with 100 ml of water with a temperature of 80 °C, after we put it in a beaker with a same quantity (100 ml) of water but with a temperature of 50 °C. You may choose between small or big bottom areas for the internal beaker.

**Follow the next steps:**

1. Select the size of the bottom for the internal beaker (area of beaker's bottom).
2. Place the small beaker (the one with hot water) into the big beaker (by clicking on the small beaker, this is automatically placed into the big one).
3. Place the thermometer into the small beaker (by clicking on the thermometer).
4. Press the button "Start" for running the experiment.

During the evolution of the virtual experiment, watch the formation of the curve on the graph.

*At which temperature is there going to be equilibrium between the quantities of the water in the internal and external beaker?*

................................................................................................................................

................................................................................................................................

................................................................................................................................

*After how much time is this equilibrium going to happen?*

................................................................................................................................

................................................................................................................................

................................................................................................................................

**For better accuracy of the above measurements, you can repeat the experiment and watch the time and temperature indications on the left side of the screen.**

**Now repeat the above steps by selecting a different area size for the bottom.**

**Fill up the next Table:**

| | SMALL BOTTOM AREA | LARGE BOTTOM AREA |
|---|---|---|
| Initial water temperature at the small internal beaker | | |
| Initial water temperature at the large external beaker | | |
| Final water temperature at the small internal beaker | | |
| Duration of final temperature restoration at the small internal beaker | | |

*So, does the time needed for a quantity of water to cool down, depend on the size of the vessel? If yes, in what way?*

## 3.3.2. HEATING OF BEAKERS WITH DIFFERENT SURFACE

Now, select the virtual experiment «Surface», «Lab2». During this virtual lab we are going to use a heater in order to heat 100 ml of water (initial temperature 20 $^oC$). We are going to follow the process till the temperature becomes high enough so that some conclusions can be made. You may choose between small or big bottom areas for the internal beaker.

**Follow the next steps:**

1. Select the size of the bottom for the internal beaker (area of beaker's bottom).
2. Place the thermometer into the small beaker (by clicking on the thermometer).
3. Press the button "Start" for running the experiment.

During the evolution of the virtual experiment, watch the formation of the line on the graph.

*Which is the higher temperature that the water in the beaker will acquire?*

*After how much time will this happen?*

*At the 7th minute, which will the temperature of the water in the beaker be?*

**For better accuracy of the above measurements, you can repeat the experiment and watch the time and temperature indications on the left side of the screen.**

**Now repeat the above steps by selecting a different area size for the bottom.**

**Fill up the next Table:**

| | SMALL BOTTOM AREA | LARGE BOTTOM AREA |
|---|---|---|
| Initial temperature of water in beaker | | |
| Temperature of water in beaker at $7^{th}$ minute | | |
| Time of intermediate measurement | 7 min | 7 min |

*So, does the time needed for a quantity of water to be heated, depend on the size of the vessel?*
*If yes, in what way?*

# 4. PROJECT ON THE THERMAL CONDUCTIVITY IN COMPOSITE MATERIALS

Students are asked to choose the appropriate material from a data bank with properties of thermal insulators and thermal conductors, in order to manufacture everyday technological artifacts.

**Excerpts from the set up are given:**

The main menu, two everyday technological artifacts using thermal conductors and three using thermal insulators are visualized:


FIG. 4.1.1 THE MAIN MENU

## I. TEAPOT:

A tea pot, with its dimensions is given. The student must choose one out of five thermal conductors to manufacture it.


FIG. 4.1.2 THE TEAPOT

The main properties of the chosen material is given and cost and weight is calculated.

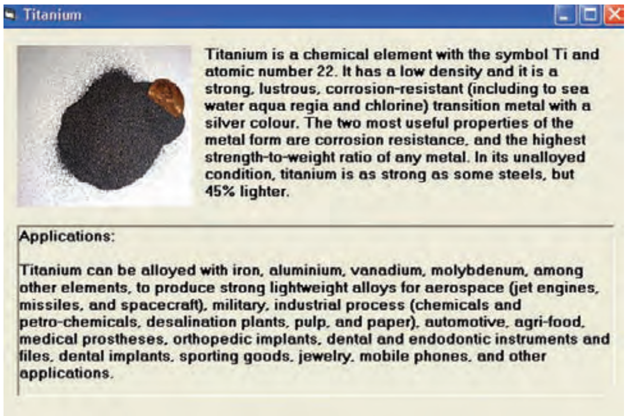



FIG. 4.1.3 TITANIUM PROPERTIES

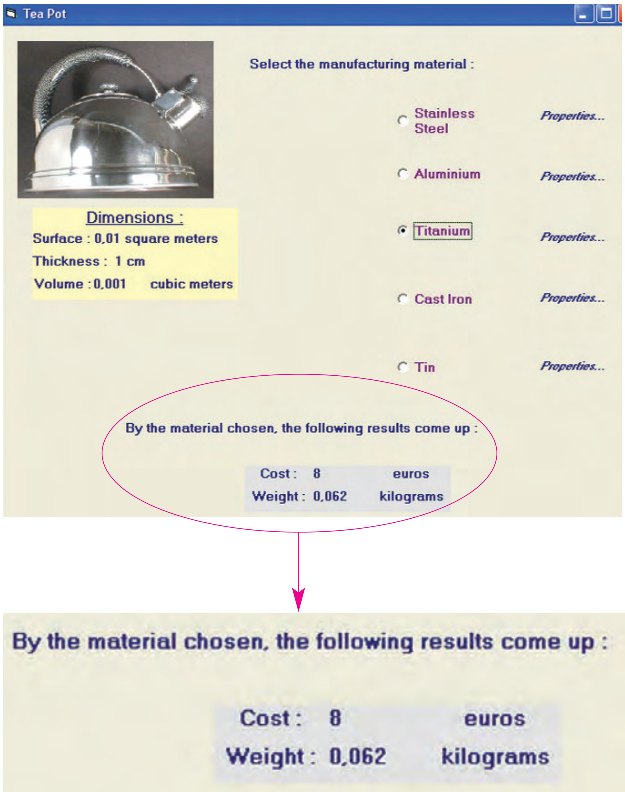



FIG. 4.1.4 COST AND WEIGHT OF THE TEAPOT, MANUFACTURED BY TITANIUM

## II. ISOTHERMIC JACKET:

An isothermic jacket, with its dimensions is given. The student must choose one out of five thermal insulators to manufacture it.

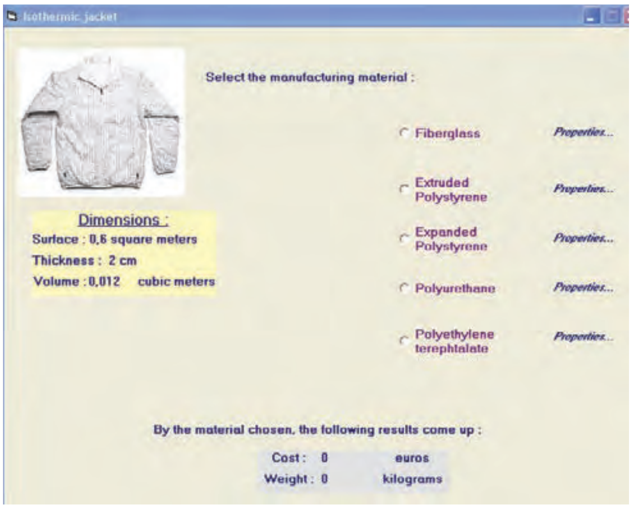



FIG. 4.1.5 AN ISOTHERMIC JACKET

The main properties of the chosen material (polyurethane) is given and cost and weight is calculated.

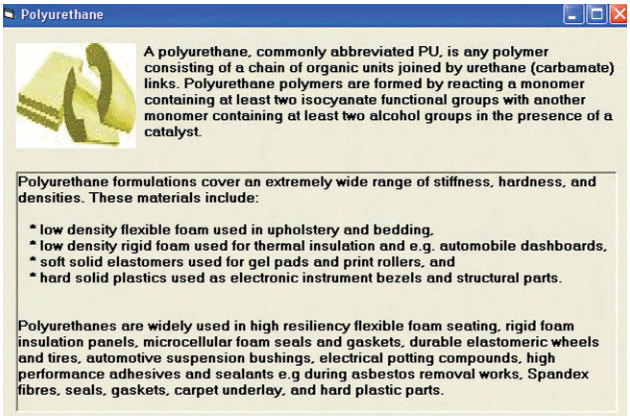



FIG. 4.1.6 POLYURETHANE PROPERTIES

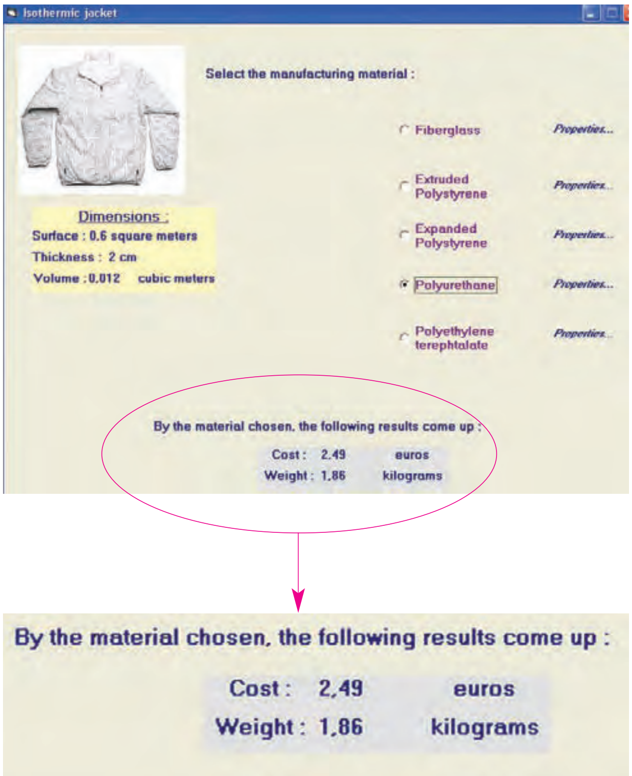



FIG. 4.1.7 COST AND WEIGHT OF AN ISOTHERMIC JACKET, MANUFACTURED BY POLYURETHANE

# D: EVALUATION TASKS

# D: EVALUATION TASKS

## 1. INTRODUCTION TO PART D

In this part the pre and post tests of the implementation of TLS 3 are included. Included also are the experimental design questionnaire, the questionnaire for the models, the protocol of the semi structured interview as well as the motivation and attitudes questionnaires. The rubrics for each of the questionnaire items are also presented in this part.

The pre-test questionnaire consists of six questions which investigate students' initial ideas in the following issues:

- Thermal equilibrium of bodies and their environment.
- The role of the environment in the insulation procedures.
- Thermal conductivity of different materials
- Ranking materials depending on their thermal conductivity.
- Microscopic explanation of thermal conduction through matter.

The post-test questionnaire consists of ten questions which investigate students' ideas after the instructional intervention in the following issues.

- Thermal equilibrium of bodies and their environment.
- Thermal conductivity of different materials
- Ranking materials depending on their thermal conductivity.
- The role of the environment in the insulation procedures.
- Microscopic explanation of thermal conduction through matter.
- Understanding of factors that make some materials more conductive than others.

The experimental design questionnaire includes one question with sub questions which test students' ability to design, observe and record data, indicate initial conditions and choose the appropriate apparatuses for carrying out an experiment.

Finally the attitudes and motivation questionnaires include a series of questions which examine students' attitudes towards science as well as their opinions about the reasons they believe science is taught.

## 2. CONCEPTUAL QUESTIONNAIRE

### 2.1. PRE-TEST QUESTIONNAIRE

1. **During winter you visit your country house in the mountains. The temperature inside the house is 6° C . There are different items left in the house.**

   *Can you predict what will the temperature of the following items be?*

**A.** a) A woolen sweater ........... °C

b) A metal saucepan ........... °C

c) A wooden table ........... °C

**B.** *Why do you think these items will have the specific temperature?*

.......................................................................................................................................................

.......................................................................................................................................................

.......................................................................................................................................................

.......................................................................................................................................................

2. **Going on a day excursion you put your hot coffee in a thermos. However you finally did not drink it.**

   *In the afternoon, when you are back home and you open the thermos will the temperature of the coffee have changed?*

   *Justify your answer.*

.......................................................................................................................................................

.......................................................................................................................................................

.......................................................................................................................................................

.......................................................................................................................................................

**3. The top of a table is wooden and its legs are made of metal. If you touch with one of your hands the top and with the other the legs you are going to feel the wooden top warmer than the metal legs. This happens because:**

| | |
|---|---|
| a) Wood absorbs and stores heat while the metal doesn't | |
| b) Metal and wood have different temperatures | |
| c) Metal conducts heat much faster than wood | |
| d) Metal absorbs cold | |

*Circle the correct in your opinion answer.*

**4. On a snowy day three friends made a snowman. Another friend was coming later and they had decided to show it to him. However, the sun came out and the temperature started rising. Thus the friends had to decide how to keep the snowman from melting.**
**Each of the friends expressed a different opinion on how to make it plausible.**

| | |
|---|---|
| a) Cover it, said one of them, with your ski jacket. It will keep it cold and will prevent him from melting | |
| b) No, said the other one, do not cover it with the ski jacket it will make it melt | |
| c) Whatever you do will make no difference, said the third one | |

*Who do you think was right?*
*Justify your answer.*

**5. A cold winter day, you and two of your friends went to the school café to drink hot chocolate. The hot chocolate was served in cups made of three different materials - plastic, metal and glass.**
**All the drinks had the same temperature the time they were served.**

**A.** *If you were the first one to pick up a cup, which of the three - glass, metal or plastic - would you choose in order to make sure that your fingers wouldn't burn?*

glass cup ☐ metal cup ☐ plastic cup ☐

*Give a brief explanation of your choice:*

**B.** *In which of the cups do you think that the chocolate would* ***cool down faster?***
*Give a brief explanation of your answer.*

**6. A friend of yours stirs the food while cooking with a metal spoon. After a while he starts feeling his fingers burning.**

*Why do you think this happens?*

*Can you explain what happens to the* ***microscopic particles of mater*** *which the metal spoon is made of?*

## 2.2.PRE-TEST QUESTIONNAIRE
### RUBRICS

**Question 1.**
All the objects will have the same temperature ($6^o$ C) because they are in a thermal equilibrium with their environment.

**Question 2.**
In the afternoon, the temperature of the coffee will be lower because, although the walls of the thermos are lined with insulating materials, heat is slowly transferred through them to the environment.

**Question 3.**

(c) The metal conducts heat much faster than wood

**Question 4.**
Option (a)
The ski jacket is lined with a thermally insulating material and it does not allow the body's heat to be conducted to the environment with the result the human body is kept warm. Respectively, it does not allow the heat to be conducted from the environment to the snowman. Thus it keeps, for a period of time, the snowman's temperature low enough so it doesn't melt.

**Question 5**
**A.**
The plastic cup.
Plastic, on the one hand is the least conductive material, and on the other, is an insulator. Thus small amounts of thermal energy will slowly be conducted to its outer surface and to the hands.

**B.**
The metal cup.
Metal, on the one hand is the most conductive material, and on the other, is a heat conductor. Thus it conducts heat to the environment much faster than the other two materials with result the coffee in the metal cup cools much faster.

**Question 6.**
The metal spoon, as a good heat conductor, allows the transfer of thermal energy. Thus heat reaches the hands of the cook.

This happens because the molecules of the food increase their kinetic energy due its high temperature. The vigorously vibrating molecules of the food transfer their kinetic energy to the molecules of the spoon. As a result these start vibrating transferring energy to the adjacent molecules which also become agitated. This continues until thermal energy is transferred through the spoon from areas of lower temperature to those of higher, until all of them acquire the same temperature.

## 2.3. POST-TEST QUESTIONNAIRE

1. **During winter you visit your country house in the mountains. The temperature inside the house is 6º C . There are different items left in the house.**

   *Can you predict what will the temperature of the following items be?*

**A.** a) A woolen sweater ........... ºC

b) A metal saucepan ........... ºC

c) A wooden table ........... ºC

**B.** *Why do you think these items will have the specific temperature?*

............................................................

............................................................

............................................................

............................................................

2. **Going on a day excursion you put your hot coffee in a thermos. However you finally did not drink it.**

   *In the afternoon, when you are back home and you open the thermos will the temperature of the coffee have changed?*

   *Justify your answer.*

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3. **The top of a table is wooden and its legs are made of metal. If you touch with one of your hands the top and with the other the legs you are going to feel the wooden top warmer than the metal legs. This happens because:**

| | |
|---|---|
| a) Wood absorbs and stores heat while the metal doesn't | |
| b) Metal and wood have different temperatures | |
| c) Metal conducts heat much faster than wood | |
| d) Metal absorbs cold | |

*Circle the correct in your opinion answer.*

**4. On a snowy day three friends made a snowman. Another friend was coming later and they had decided to show it to him. However, the sun came out and the temperature started rising. Thus the friends had to decide how to keep the snowman from melting.**
**Each of the friends expressed a different opinion on how to make it plausible.**

| | |
|---|---|
| a) Cover it, said one of them, with your ski jacket. It will keep it cold and will prevent him from melting | |
| b) No, said the other one, do not cover it with the ski jacket it will make it melt | |
| c) Whatever you do will make no difference, said the third one | |

*Who do you think was right?*
*Justify your answer.*

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**5. A cold winter day, you and two of your friends went to the school café to drink hot chocolate. The hot chocolate was served in cups made of three different materials - plastic, metal and glass. All the drinks had the same temperature the time they were served.**

**A.** *If you were the first one to pick up a cup, which of the three - glass, metal or plastic - would you choose in order to make sure that your fingers wouldn't burn?*

glass cup ☐ metal cup ☐ plastic cup ☐

*Give a brief explanation of your choice:*

..................................................

..................................................

..................................................

..................................................

**B.** *In which of the cups do you think that the chocolate would **cool down faster?***
*Give a brief explanation of your answer.*

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**6.** **A friend of yours stirs the food while cooking with a metal spoon. After a while he starts feeling his fingers burning.**

*Why do you think this happens?*

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*Can you explain what happens to the* ***microscopic particles of mater*** *which the metal spoon is made of?*

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**7.** **When you stir the hot food in the saucepan with a plastic spoon for quite some time do you think that your fingers will start burning?**

*Justify your answer.*

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**8.** **Complete the following sentences using the correct word:**

Heat conductors are called the materials which.................................................

Insulators are called the materials which ..........................................................

**9.** **In the following two figures the microscopic structure of materials belonging to two different categories is shown.**

*Can you tell which of these materials conducts heat faster?*
*Justify your answer.*

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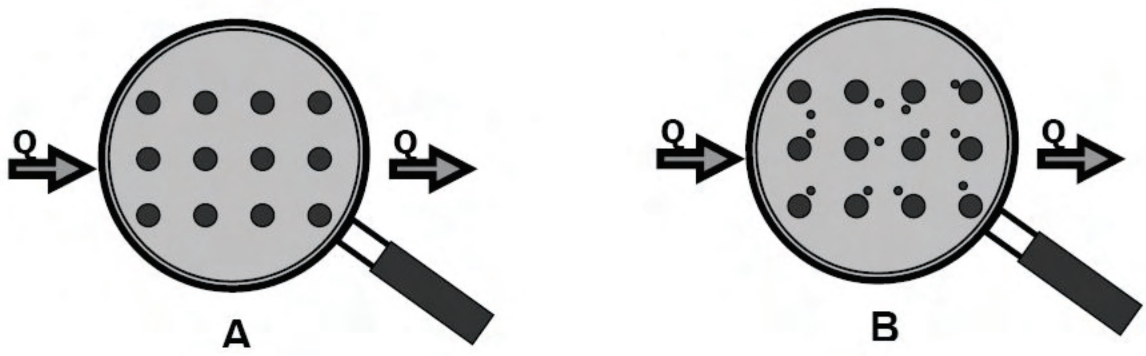
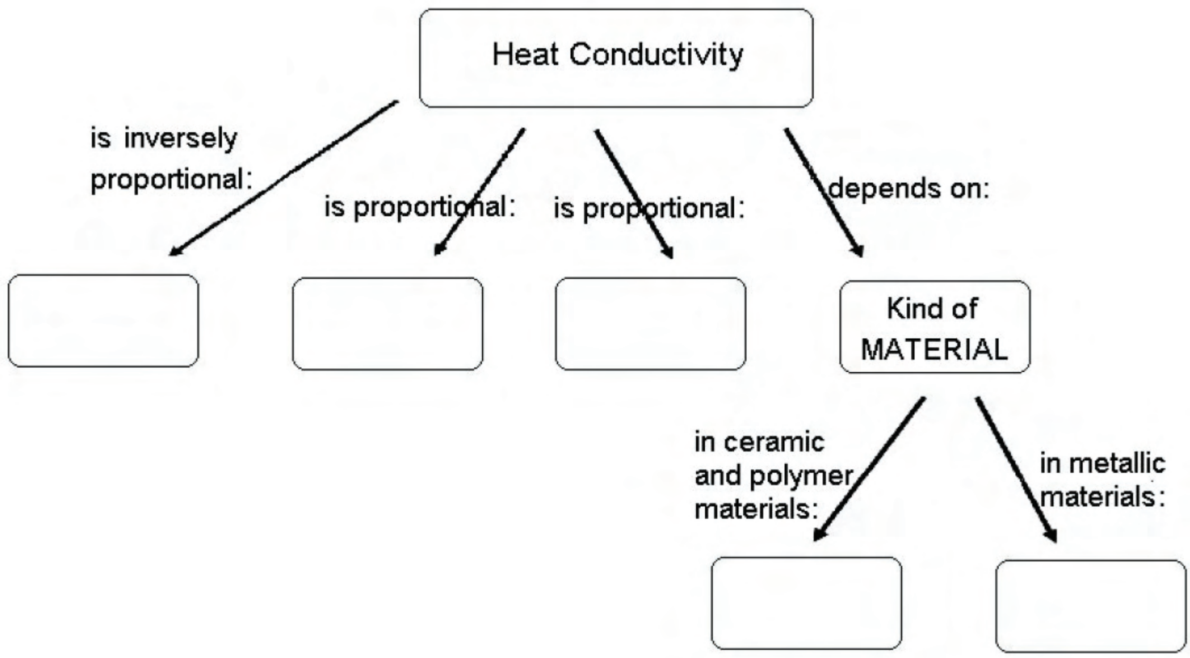



**10.** **10. In the following concept map place the concepts in the correct box:**

thickness (d), density (ρ), temperature difference (ΔT), surface area (A), electrons (e)



## 2.4. POST-TEST QUESTIONNAIRE

### RUBRICS

**Question 1.**
All the objects will have the same temperature (6$^{o}$ C) because they are in a thermal equilibrium with their environment.

**Question 2.**
In the afternoon, the temperature of the coffee will be lower because, although the walls of the thermos are lined with insulating materials, heat is slowly transferred through them to the environment.

**Question 3.**
(c) The metal conducts heat much faster than wood

**Question 4.**
Option (a)
The ski jacket is lined with a thermally insulating material and it does not allow the body's heat to be conducted to the environment with the result the human body is kept warm. Respectively, it does not allow the heat to be conducted from the environment to the snowman. Thus it keeps, for a period of time, the snowman's temperature low enough so it doesn't melt.

**Question 5**
**A.**
The plastic cup.
Plastic, on the one hand is the least conductive material, and on the other, is an insulator. Thus small amounts of thermal energy will slowly be conducted to its outer surface and to the hands.

**B.**
The metal cup.
Metal, on the one hand is the most conductive material, and on the other, is a heat conductor. Thus it conducts heat to the environment much faster than the other two materials with result the coffee in the metal cup cools much faster.

**Question 6.**
The metal spoon, as a good heat conductor, allows the transfer of thermal energy. Thus heat reaches the hands of the cook.

This happens because the molecules of the food increase their kinetic energy due its high temperature. The vigorously vibrating molecules of the food transfer their kinetic energy to the molecules of the spoon. As a result these start vibrating transferring energy to the adjacent molecules which also become agitated. This continues until thermal energy is transferred through the spoon from areas of lower temperature to those of higher, until all of them acquire the same temperature.

**Question 7.**
The fingers will feel the spoon slightly warm but not hot. Plastic is a heat insulator thus small amounts of thermal energy will gradually reach the other end of the spoon and the fingers.

**Question 8.**
Heat conductors are called the materials which … *are capable of readily conducting heat.*
Insulators are called the materials which … *slow down the heat transfer.*

**Question 9.**
Material B will conduct heat faster due to the existence of free electrons.

**Question 10.**
From left:
thickness (d), temperature difference ($\Delta T$), surface area (A)

Kind of Material:
density ($\rho$), electrons (e)

# 3. EXPERIMENTAL QUESTIONNAIRE

## 3.1. POST-TEST QUESTIONNAIRE

**Kate has two heat resistant mugs, "A" and "B". Both mugs are similar, except that they are made of different materials. Kate claims that if we put the mugs on a heater, the water in mug "A" warms up faster that the water in mug "B".**

*How will you find out if she is right?*

*Can you set up an experiment to check her statement?*

*What will you need?*

*What will you observe?*

## 3.2. RUBRICS

To find out if the statement is right (or not) we need to perform the following experiment: We take two mugs made of these different materials as mug "A" and mug "B", and we pour in the same amount of tab water at the same (room) temperature.

Both mugs should be of the same size and thickness. We will need one heater, two thermometers and a timer. We put in the thermometers and we start heating the two mugs at the same time. We monitor the temperature change versus time in the two thermometers.

As the heat supply is the same for both mugs, if Kate was right, then, after some time, temperature in mug "A" should be higher than that in mug "B". If Kate was wrong, the opposite should be observed.

# 4. MODELLING

## 4.1. PRE-TEST AND POST-TEST QUESTIONNAIRE

**A1.** *What do you think that a scientific model represent? Justify your answer and give two examples.*

**A2.** *Do you think that a scientific model should represent the reality exactly as it is or not? Justify your answer.*

**A3.** *What do you think is the purpose of a scientific model? For what reason can the model be used?*

**A4.** *Do you think that a scientific model is a powerful research tool or not? Justify your answer by referring two reasons for that.*

## 4.2. RUBRICS

**A1.**
A scientific model represents an idea, a theory that helps us to try to interpret and/or predict the real world. It can be a figure, a drawing, a simulation, an equation, everything that represents an idea of something.
Example 1: a simulation that represents the different motion of the particles in a solid, a liquid and a gas.
Example 2: the equation of the conservation of the momentum.

**A2.**
A scientific model shouldn't represent the reality exactly as it is because the purpose of a model is not to represent the reality but its' purpose is to represent our ideas or theories about what we see to happen in the real world. Usually models are made to be as simple as possible in order to give us the opportunity to concentrate on one parameter of the phenomenon that we study.

**A3.**
The purpose of the model is to describe, explain, and predict a phenomenon or generally, the real world. The model comprises a stimulus for thinking and a powerful research tool.

**A4.**
Yes, the scientific model is a powerful research tool because the scientist can express his ideas or theories with it and after that he can compare the data of the model with the data of the experiment in order to check his ideas. Moreover, a scientific model comprises a stimulus for thinking and a powerful communication tool through the scientific community.

## 4.3. PROTOCOL OF SEMI-STRUCTURED INTERVIEW

**Protocol of semi-structurred individual interview about models**

The aim of Teaching Learning Sequence, as implemented from UOT workgroup was the improvement of students' awareness about the nature, the purpose and the usefulness of scientific models through appropriate designed activities aiming to gradual bridging between reality and models. More specifically, the ascertainment of models attributes and their strength and weakness were intended by the students. Nevertheless, students had to discriminate models and reality and understood that models are considered as simplifications or abstractions of reality in order to represent, interpret of predict phenomena.

In order to elicit students' ideas about the nature and propose of scientific models before and after the implementation of Teaching Learning Sequence, a semi-structured interview protocol was designed. During this process, through appropriate prompts student reveal their ideas for the following issues:

- What do you believe that a scientific model is? What could it represent? Give an example.
- How accurately should a scientific model represent the reality? Justify your answer.
- Is it possible for a scientific model to change? Yes or no? Why?
- Could there be different models for the same phenomena? Yes or no? Why?
- Which could be the purpose of a scientific model? How it might be useful?

# 5. EVALUATION AND MOTIVATION QUESTIONNAIRE

## 5.1. PRE-TEST AND POST-TEST EVALUATION QUESTIONNAIRE

EVALUATION OF SCIENCE INQUIRY ACTIVITIES STUDENT NUMBER: ..................

DATE: .................................. NAME: ..........................................................................................................................

**For each of the following statements dealing with scientific inquiry activities, please indicate how true it is for you, using the following scale: not at all true (1) … very true (7)**

| | WHEN I ENGAGE IN SCIENCE INQUIRY ACTIVITY … | NOT AT ALL TRUE | | | SOMEWHAT TRUE | | | VERY TRUE |
|---|---|---|---|---|---|---|---|---|
| 1. | I enjoy the activity very much. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2. | I think I am pretty good at the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3. | I put a lot of effort into the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 4. | I did not feel nervous at all while doing the activity | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 5. | I believe I had some choice about doing the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 6. | I believe the activity has some value for me. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 7. | I feel really distant from my peers while doing the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 8. | The activity is fun to do. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 9. | I think I do the activity pretty well, compared to other students. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 10. | I didn't try very hard to do well at the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 11. | I felt very tense while doing the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 12. | I felt like it was not my own choice to do the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 13. | I think that doing the activity is useful for my science studies. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 14. | I really doubt that my peers and I would ever be successful team through the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 15. | The activity is boring. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 16. | After working at the activity for a while I feel pretty competent. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 17. | I tried very hard on the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 18. | It was important to me to do well at the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 19. | I was very relaxed in doing the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 20. | I didn't really have a choice about doing the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 21. | I think the activity is important to do because it can help me in learning | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| | WHEN I ENGAGE IN SCIENCE INQUIRY ACTIVITY … | NOT AT ALL TRUE | | | SOMEWHAT TRUE | | | VERY TRUE |
|---|---|---|---|---|---|---|---|---|
| 22. | I feel I could really trust my peers participating in the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 23. | The activity did not hold my attention at all. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 24. | I am satisfied with my performance at the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 25. | I didn't put much energy into the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 26. | I was anxious while working on the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 27. | I felt like I had to do the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 28. | I would be willing to do similar activities more because they have value for me. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 29. | I'd like to interact with my peers participating in the activity more often. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 30. | I would describe the activity as very interesting. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 31. | I am pretty skilled at the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 32. | I felt pressured while doing the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 33. | I do the activity because I have no other choice. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 34. | I think doing the activity could help me to learn science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 35. | I feel close to my peers during the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 36. | I think the activity is quite enjoyable. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 37. | I couldn't do the activity very well. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 38. | I do the activity because I want to do it. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 39. | I believe that doing the activity could be beneficial for me. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 40. | I don't feel like I could really trust my peers who are participating in the activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 41. | When I am doing the activity, I think about how much I am enjoying it. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 42. | I do the activity because I have to do. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 43. | I think the activity is an important activity. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

## 5.2. PRE-TEST AND POST-TEST MOTIVATION QUESTIONNAIRE

ACADEMIC MOTIVATION FOR LEARNING SCIENCE          STUDENT NUMBER: ..................

DATE: ......................          NAME: ..................................................

**Using the scale below, indicate to what extent each of the following items presently corresponds to one of the reasons why you learn science.**

| Does not correspond at all **(DNCAT)** | | | Corresponds a little | Corresponds moderately **(CM)** | Corresponds a lot | | Corresponds exactly **(CE)** |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | | 4 | 5 | 6 | 7 |

| | WHY DO I LEARN SCIENCE? | DNCAT | | | CM | | | CE |
|---|---|---|---|---|---|---|---|---|
| 1. | Because I have the impression that it is expected of me. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2. | To show myself that I am a good student. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3. | Because I choose to be the kind of person who knows many things as an adult. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 4. | Because it's important to me to learn science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 5. | Because I enjoy the feeling of acquiring knowledge about science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 6. | For the enjoyment I experience when I grasp a difficult subject in science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 7. | Because it will help me make a better choice regarding my career orientation. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 8. | For the "high" feeling that I experience when I am taken by discussions with interesting science teachers. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 9. | Because studying science allows me to continue to learn about many things that interest me. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 10. | Because I think it is good for my personal development. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 11. | For the pleasure that I experience in knowing more about science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 12. | Because I would feel ashamed if I couldn't discuss with my friends about things concerning science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 13. | I don't know why I study science, and frankly, I don't give a damn. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 14. | In order to get a more prestigious job later on. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 15. | For the "high" feeling that I experience while reading about various interesting science subjects. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 16. | Because science learning allows me to experience a personal satisfaction in my quest for excellence in my studies. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 17. | Because I really like science learning. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| | WHY DO I LEARN SCIENCE? | DNC AT | | | CM | | | CE |
|---|---|---|---|---|---|---|---|---|
| 18. | Because I would feel guilty if I didn't study science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 19. | Because I'll get in trouble if I don't do so. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 20. | For the pleasure I experience when surpassing myself in science studies. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 21. | Honestly, I don't know, I truly have the impression of wasting my time in studying science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 22. | I once had good reasons for learning science; however, now I wonder whether I should continue. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 23. | Because I choose to be the kind of person who knows matters concerning science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 24. | For the satisfaction I feel when I am in the process of accomplishing difficult exercises in science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 25. | Because I want the teacher to think I'm a good student. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 26. | For the satisfied feeling I get in finding out new things. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 27. | Because for me, science learning is fun. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 28. | I don't know why I am studying science. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 29. | In order to have a better salary later on. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

# E: A BRIEF DESCRIPTION OF THE MODULE DEVELOPMENT AND ITS EMPIRICAL STUDIES

# E: A BRIEF DESCRIPTION OF THE MODULE DEVELOPMENT AND ITS EMPIRICAL STUDIES

## 1. A DEVELOPMENTAL PERSPECTIVE

### 1.1. COMBINING RESEARCH AND DEVELOPMENT

Several science education researchers have started making use of significant empirical and theoretical developments in order to improve science teaching. Researchers are interested in designing, trying out and evaluating specific activities such as bridging analogies, experiments enhancing cognitive conflict teaching, approaches such as those aiming at conceptual change units or topic-oriented teaching sequences, in specific phenomenological fields in a variety of educational contexts. An assumption shared by several science educators is that scientific understanding involves several aspects of scientific inquiry: understanding representations of the material world in terms of concepts and models, but also ways of linking representations with material phenomena and intervention procedures onto the material world. Enhancement of student interactions with the material world in laboratory settings has remained, at least for several researchers, an important focus of constructivist teaching approaches, a position which has been enhanced by development in ICT and approaches aspiring to inquiry teaching.

We may distinguish two directions focusing primarily on the development of more effective constructivist approaches to teaching science: one on students' learning and the other on the representation of scientific knowledge (conceptual and/or procedural). In the first, following the modeling of student's conceptions in the context of a scientific topic, the research and development focus on the monitoring and the microanalysis of student conceptual evolution and their learning outcomes. In the second, the research focus is on the transformation of scientific knowledge according to instructional aims into knowledge adapted to students' conceptions and the evolution of these conceptions during teaching (Fensham, 2001). Here, work on innovative content representations and their links with the material world, though arguably not widely disseminated moved away from reflections on, say, the difficult aspects of scientific content and the design of new experiments towards developing knowledge to be taught that can be learned by the students.

One developing practice aimed at combining the above directions involves the development of topic-oriented sequences in various areas, such as optics, structure of matter, heat, electricity and fluids, by researchers who consider that the learning of science is a constructive activity and treat the usual science content as problematic (Meheut and Psillos 2004). The term teaching-learning sequence (TLS) is used to identify the potential construction of fruitful links between the designed teaching and expected student learning as a distinguishing feature of a research-based medium-scale curriculum development aiming at bringing research and teaching closer, in several contexts, than is the normal practice. A TLS is often both a research process and a product which includes well researched teaching/learning activities. Often a TLS develops gradually out of several applications according to a cycling evolutionary process enlightened by research data, which results in the enrichment of this TLS with empirically validated expected student outcomes from the planned activities.

In line with the aim of the Materials Science Project we follow the trend, which involves the development of topic-oriented teaching learning sequences in various areas, by science educators who consider that the learning of science is a constructive activity, and treat the usual science content as amenable to educational transformation. A research based module like the one in conductivity is in effect a teaching learning sequence and the term module is used in this paper interchangeably with teaching learning sequence.

During the course of the project we have developed one initial TLS, which we call TLS1 and subsequently, following iterative development through application and redesign TLS2 and TLS 3.

### 1.2. DESIGNING A TLS

The development of a TLS has become the focus of several theoretical and empirical studies. However, the explicit and implicit assumptions and decisions that affect, to a considerable degree, the design and development of the corresponding teaching approaches are less widely treated and may not even be clearly presented. The construction of a teaching content adapted to students' minds seems to involve implicit expertise and special practices on the part of the researchers. For example, the developers' underlying assumptions, which inevitably bear upon the design of the sequences, are hardly ever made explicit. This makes the communication and replication of teaching approaches, beyond broad assumptions, problematic even in widely discussed areas like the structure of matter or simple electrical circuits, and raises concerns about the validity of these approaches in different contexts. Several proposals by researchers are taken into account here.

At the theoretical level, the "educational reconstruction" model is among the suggested models which provides a framework for designing and studying a module. This model links closely considerations on the science concept structure with analysis of the educational significance of the content in question, as well as with empirical studies on students' learning processes and interests (Kattman. et. al, 1995). The model has three main components. The content structure is analysed from the scientific point of view and from the perspectives of the educational aims set in the first component. The educational analysis includes studies in which way the content to be taught is linked to the other topics of instruction, to what extent it is 'exemplary' for other contents and what current and future meaning it has for students and society. These guide the process of 'constructing the core ideas of the content. Empirical studies on learning and teaching are another component of the model. Instruction is developed and evaluated in the third component. A special characteristic of the model is its systemic character which means that knowledge gained in one of the components influences the activities and the interpretation of the results of the other components.

Results of the analysis of the content structure (linking clarification of the core concepts and analysis of the educational significance) as well as preliminary ideas of construction of instruction play an important role in planning empirical studies on teaching and learning. The results of empirical studies, on the other hand, influence the processes of educational analysis, the setting of new goals and objectives in detail. The science content structure and the students' conceptions and frames of interpretation are seen as being equally important parameters in the process of educational reconstruction and are necessary to attain the goals of science teaching. The model of educational reconstruction takes into account that the science content structure may not be simply transferred (perhaps in a somewhat simplified manner) into science instruction. Content has to be constructed on the grounds of an analysis of the educational significance of the content and on the basis of students' learning difficulties.

## 2. RESEARCH AND DEVELOPMENT IN TEACHING LEARNING SEQUENCE 1 (TLS1)

### 2.1. SETTING THE AIMS OF TLS1

The module aims at facilitating students to construct a deeper understanding of thermal conductivity of materials than it is normally taught in, at least the Greek Curriculum. At the same time the module makes use of conductivity as a topic for introducing students to aspects of scientific inquiry. In the design of the module it has been taken into account that both teachers and students are normally familiar with traditional transfer of knowledge approaches rather that inquiry ones. This topic deals with materials and phenomena that are common, affect everyday life and can be studied at different levels. Students study thermal conductivity in a range of conductive and non conductive materials from different perspectives. At the phenomenological they carry out experimental investigations, make observations and handle situations that are familiar to them. At the microscopic level students explore and play with microscopic didactically transposed models of metals and ceramics. These models are not constructed by the students but they are provided to them in order to explore their function. Several applications of insulating and conductive materials provide a framework for motivating students to study the topic and link their knowledge with interesting applications.

The module is not introductory to the topic of heat and temperature but it is designed as an extended theme, which may be used by the teachers in a flexible time zone during curriculum activities. Such extensions have been often suggested as part of various curricula including the current Greek one.

In this context the aims of the module include conceptual knowledge as well as investigative skills. The aims of the final TLS3 are outlined in Part A §5. However, the initial aims for TLS1 did not include the ones on experimental planning since the main focus in TLS1 was conceptual understanding and carrying out investigations by students by students who are familiar with traditional teaching and would be initiated in inquiry.

### 2.2. STUDENTS' CONCEPTIONS AND DIFFICULTIES

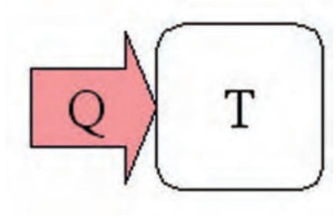
In developing TLS1 we carried out analysis of research results in order to identify students' conceptions about heat, temperature and specifically heat transfer. An overview of such research results is presented and discussed in Part A §4.

### 2.3. TEACHING MODELS AND DESIGN OF RESOURCES

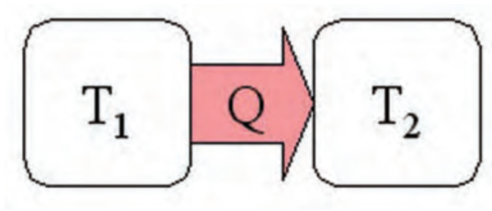
We consider that understanding of conductivity implies educational transformation of scientific knowledge at different levels. Macroscopic and microscopic scientific models of conductivity must be adapted to students and transformed into coherent teaching models in order to be learnable. Students will then be engaged in model exploration and construction of links between models as well as models and properties of materials (Gilbert & Boulter, 1998).

i) Concerning macroscopic models we may note the following: To illustrate the thermal interactions either in a two-body case, or in a single body, as depicted in figures 1a and 1b, researchers have used the so-called "heat flow" model. Though research has shown that "heat flow" model seems appealing to students (Linn & Muilenburg, 1996), yet, it does not focus on the thermal conductivity of materials. For this reason we opted to modify the "heat flow" model, as to incorporate material properties and specifically thermal conductivity (fig. 1c, 1d).

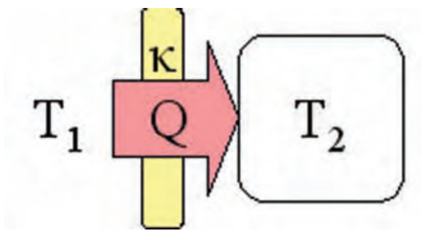
In reference to figure 1, the first of the models (fig. 1a) represents a single-body heat flow model; heat is flown in the body, causing a raise in its temperature. A typical example is a calorimetric experiment. In this example, one does not cares why heat is flown; it is taken per se. This question is addressed in the second of the models (fig. 1b), where, heat is transferred from a body with higher temperature ($T_1$) to another with lower ($T_2$). A typical example for such a 2-body thermal interaction is the experiment of thermal equilibrium. The model, shown in fig. 1c, is a 2-body model that extends the model 2b; the heat flows in the body through a barrier of thermal conductivity "κ". It is a more realistic example, for heating water for example, inside a beaker; the rate of heat transfer depends on the temperature difference (T1-T2) as well as on the beaker's surface, thickness and thermal conductivity. Similarly, the model shown in fig. 1d, is a 3-body



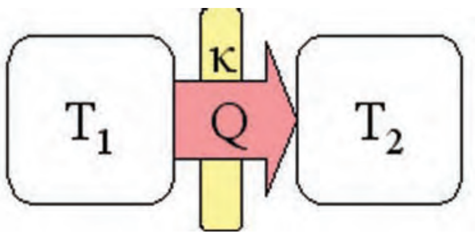

(A) ONE BODY MODEL




(B) TWO BODY MODEL




(C) TWO BODY MODEL




(D) THREE BODY MODEL

FIGURE 1: HEAT FLOW MODELS

model, which extends model 1b. Extended models try to address the question **"how fast does the heat flow".**

In this context we developed a series of experiments including simulated ones as mentioned in Part A §7.3, SimLab 6. These depict several aspects of heat transfer (material, thickness, area), and follow the above mentioned extended "heat flow" model "c" and "d". For example, the Flash simulation, shown in Figure 2, consists of two beakers one inside the other. In this simulated experiment, which follows the type

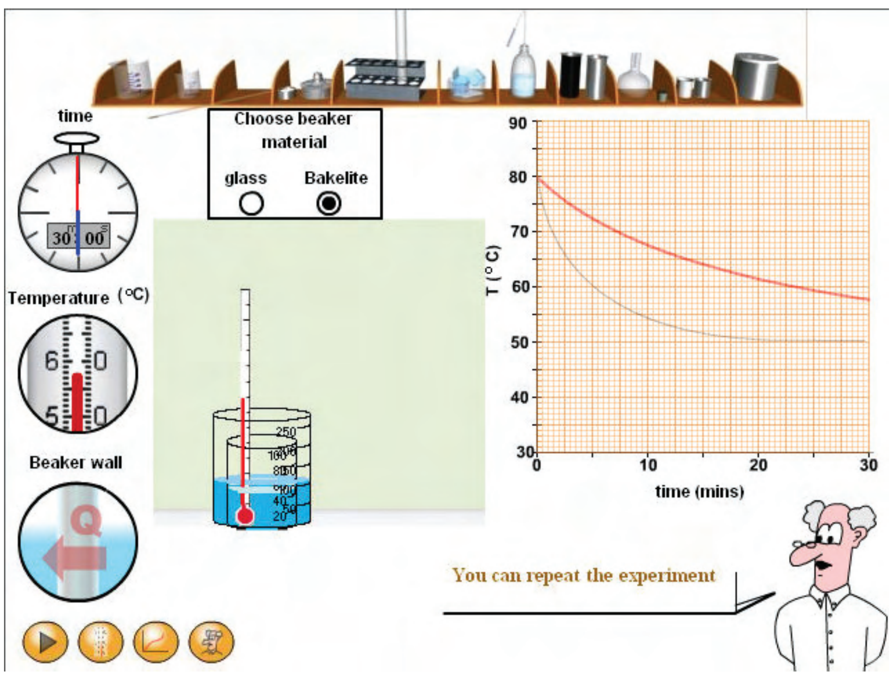



FIGURE 2: SIMULATED EXPERIMENT BASED ON TYPE "D" HEAT FLOW MODEL

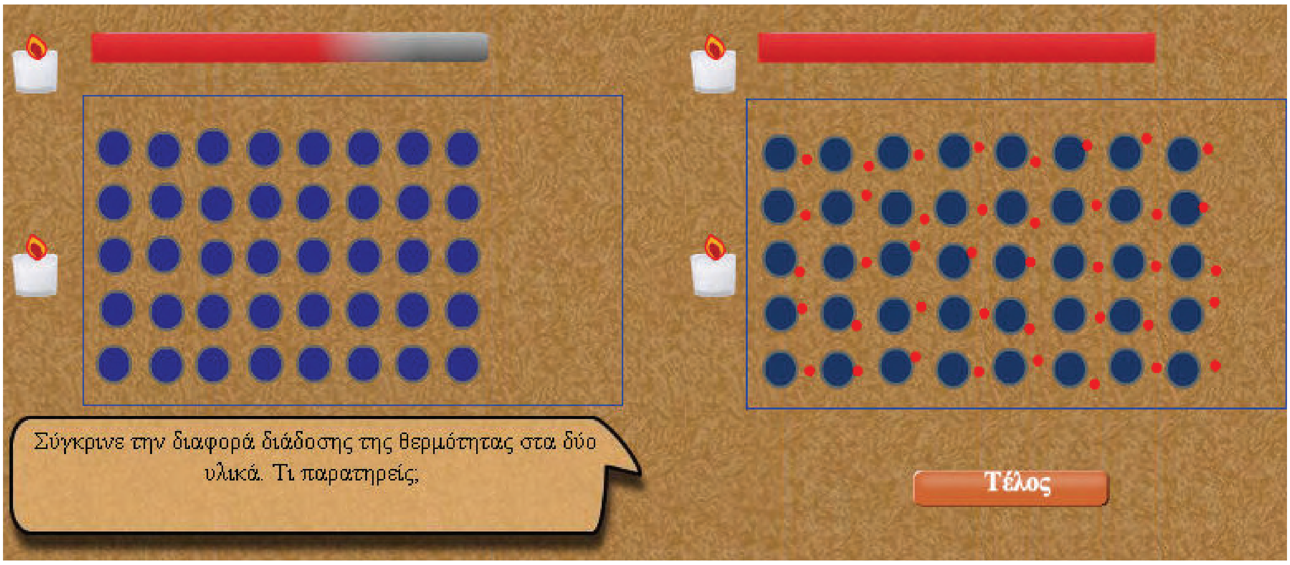



FIGURE 3: SIMULATED MICROSCOPIC MODEL FOR THE HEAT CONDUCTION IN CERAMICS AND IN METALS.

”d” of the extended “heat flow” model, the role of material is investigated. The experiment is setup up by clicking on the small beaker and on the thermometer, according to the virtual teacher’s instructions. The small beaker contains 50ml of water at 80°C while the larger one 50ml of water at 20°C. The time, temperature, and a zoom in the beaker’s wall are shown in the three circles on the left-most side of the simulation. A red arrow indicates the rate of the heat transfer from the inner beaker to the outer, dimming upon the value of heat transfer.

ii) As outlined in Part-A (par. 7.4) the problem of heating up a rod of material at one end of it is a rather complex one, as it involves, the heating up of the point where heat is applied, which is related to the specific heat of the material. Then, heat is propagated through the material at a rate which is proportional to the thermal conductivity. Cold parts of the rod are heated up, at a rate related to the specific heat and finally, hotter parts of the material radiate heat to the surrounding environment.

At the microscopic level, we developed special simulated teaching models in order to illustrate underlying processes for thermal conduction in ceramics and metals. The design of these teaching models is based on several assumptions and simplifications concerning the function and visualization of heat conduction which are set out in Part A §7.4.3. The actual scientific models are presented in Part A §3. In this context the design and development for the simulated (macroscopic) experiments followed several phases. A typical simulation in its initial phase is shown in Figure 3. All texts and messages were in Greek, programmed hard-core inside the simulation. In our microscopic simulations, we consider the heat conduction in a transient state. As can be seen in Fig. 3 the rod is heated up, in one end, and we observe the evaluation on the temperature gradient profile during the heating process. The microscopic simulations actually indicate the transient process: the columns of atoms are gradually changing the amplitude of their oscillatory motion as heat propagates through the solid. This change in amplitude of oscillatory motion is due to the transient heat transfer. A typical screen-shot of a microscopic model is presented in figure 3.

The 1st version of our microscopic simulations consisted of two frames. In the model frame the particles were oscillating initially at low amplitude and as the heat propagated through out the material the amplitude of the vibration changed, and the color in the material gradually changes to bright red. No thermal gradient was considered through out the material.

## 2.4. DESIGN OF INSTRUCTION

Science as inquiry is pursued in the module, which is structured in units. Students conduct guided investigations, use appropriate real and virtual experiments, explore scientific models and construct links between evidence and explanations in order to be initiated both in the experimental aspect of inquiry as well as the representational one. Units include an introductory familiarization phase, where contextualized everyday-life problems are presented to students. Several units are based on laboratory type sessions in which students interact with hands-on and simulated experiments and make macroscopic observations following structured worksheets in terms of the Predict-Observe-Explain strategy. Microscopic models are presented by the teachers and then explored by the students. Students work in groups, solve problems, explore models and are engaged in classroom discussion on the problem under study. The underlying design theses are presented in section A §6. In the initial TLS1 theses A §6 III 2, III 3 and 4 were not taken into account.

Taking into account the above theses and principles we developed an 9 hour sequence after working out the content and activities in the Local Working Group and making some preliminary small scale trials of materials with students. We developed units on thermal equilibrium experiments, heat conduction in different materials, thermal conductivity in ceramics, thermal conductivity in metals, size of surface and thickness as a factor that affects heat transfer and thermal conductivity in composite materials.

An overview of the suggested structure and content of TLS1 is provided below.

### 2.5. CONTENT AND STRUCTURE OF TLS1

An overview of the suggested structure and content of TLS1 is provided below. Units 1, 5 and 6 are expected to take place in one teaching hour while Units 2, 3 and 4 are expected to take place in two teaching hours.

| | |
|---|---|
| **UNIT 1**<br>**(1 HR)** | Students study thermal interaction between quantities of water having the same temperature in cups made of different materials, during their cooling down and rank the materials used, according to their thermal conductivity. |
| **UNIT 2**<br>**(2 HRS)** | Students study conductivity in ceramics.<br>Students explore the role of the oscillation of particles of the lattice in thermal conduction in ceramics and interpret thermal conduction (microscopic aspect). Crystalline and amorphous ceramics are treated separately.<br>Students explore the role of density of ceramics materials in effecting heat conduction (microscopic aspect and then macroscopic via experimental procedure).<br>Students associate experimental findings with theoretical predictions. |
| **UNIT 3**<br>**(2 HRS)** | Students study conductivity in metals.<br>Students explore the role of the oscillation of particles of the lattice as well as the role of free electrons in thermal conduction in metals and interpret thermal conduction (microscopic aspect).<br>Students compare the mechanism in thermal conduction between ceramics and metals in a microscopic aspect.<br>Students explore thermal conduction in alloys (microscopic aspect).<br>Students study experimental techniques such as use of thermographic paper to detect heat conduction and rank metallic rods according to their thermal conductivity.<br>The use of conductors in house and everyday situations is discussed. |

| | |
|---|---|
| **UNIT 4** (2 HRS) | Students carry out investigations in simulated lab on how the size of the thickness of walls of a vessel as well as their surface area affect thermal conduction in both heating and cooling situations. |
| **UNIT 5** (1 HR) | Students study conductivity in composite materials.<br>Students explore the role of the air in thermal conduction in composite materials (microscopic aspect).<br>Students compare the mechanism in thermal conduction between ceramics, metals and composite materials in a microscopic aspect. |
| **UNIT 6** (1 HR) | Students discuss and reflect on taught knowledge and applications about composite materials<br>The students apply the taught knowledge to interpret everyday situations as eg. The thermal insulation of a house. |

## 2.6. EMPIRICAL STUDY OF TLS1: IMPLEMENTATION AND DATA COLLECTION AND RESULTS

In this context we have planned research, which broadly aims at providing evidence for the effectiveness and the gradual development of the module in enhancing students' understanding of thermal conduction. Selected results of these studies are presented below.

### 2.6.1. CONTEXT

The initially designed Teaching Learning Sequence (TLS) was implemented in two stages:

- In the first stage, implementation was carried out in a school in Northern Greece and in a group of 12 students.
- The second stage of implementation took place in a suburban area of a public school of Thessaloniki, which was attended by students of low to medium income. The total number of the treated students was 67. Lessons were video recorded.

The teachers were specialists in physics and held University degrees.

Both stages were carried out in the second half of the spring semester of the year 2008.

### 2.6.2. DATA COLLECTION

Data were collected by several means. Continuous data were obtained through video based observations of classroom interactions. Teachers' notes were used as well. A pre post design was followed for investigating students' conceptual development. Specially developed questionnaires were used as well as and semi structured interviews of selected students.

Prior to the implementation of the module students' ideas were investigated. A questionnaire consisting of 9 questions was used. Questions were events and experiences from every day life (see selected items in Appendix). Students were asked to give written documentation of their choices. Students' ideas were investigated, among others, on thermal equilibrium and insulation, ranking materials depending on their thermal conductivity, heat conduction through mater, microscopic processes, heat conduction and the role of the parameters of surface 'area' and 'thickness,' students' ability to interpret a graphical representation of a thermal phenomenon, which was verbally described, temperature and thermal conductivity of materials. A post-test questionnaire featuring the pre-test questions and additional new ones (see selected items in Appendix) concerning the new issues introduced by the TLS was administered to the students at the end of the TLS implementation. Besides, in order to track students' understanding of the microscopic process of heat conduction which was considered one of the most difficult issues introduced by the TLS, a 'one question test' was administered mid way of the implementation of the whole TLS.

### 2.6.3. RESULTS

Qualitative analysis of the students' written documentation was employed. The procedure used identification of regularities in the first stage followed by a constant comparative technique.

Sixty seven (67) questionnaires were analyzed. The analysis showed the following trends in students' ideas and explanations.

#### 2.6.3.1. STUDENTS' RESPONSES TO THE PRE-TEST QUESTIONNAIRE

Thermal equilibrium between bodies and their environment:

1. Students did not realize that bodies that have been for sufficient time in a room acquire the room temperature. The main ideas detected in students' explanations were:
   a) The temperature each body has depends on the material it is made of.
   b) The temperature each body has depends on the thermal conductivity of the material.
   c) The temperature the bodies have depends either on their mass and volume or on the size of their surface (small percentage).

Only one answer can be characterized as "almost correct". There were irrelevant explanations and choices without documentation. There was also a combination of the above reported ideas in students' explanations.

**Thermal equilibrium between two adjacent bodies of different temperature:**

It should be noted here that the students who completed the questionnaire had discussed thermal equilibrium between two bodies, before the module was introduced, in another section of the "Heat and Temperature" chapter of the Physics school text book.

The question used for detecting students' ideas on the above issue was that concerning thermal equilibrium between a thermometer and the human body. This question had two scientifically acceptable choices:

1. That a thermometer shows the real temperature of the human body when both human body and thermometer have the same temperature
2. That a thermometer shows the real temperature of the human body when heat stops flowing from the body to the thermometer.

Students who are considered to have given a scientifically acceptable explanation chose either one but non both of them. They did not seem to realize that in both cases bodies are in thermal equilibrium.

In the rest students' explanations for either of these choices there were Teleological explanations: Those which attempt to explain events in terms of ends, goals, or final purposes. These are: a) that thermometers basic purpose is to show the body's temperature, b) that the purpose of heat flow is for allowing us to find out what the body's temperature is.

In the rest there were detected explanations that are not backed by logic or understanding or contain scientifically invalid and logically incoherent information in a good percentage of the explanations, and explanations considering that the time a thermometer shows the real temperature of the human body depends on the type of the thermometer.

**Thermal insulation and the role of the environment**

In this question, the most interesting finding to which the choice of answer of almost 2/3rds of the students can be interpreted is that they seem to believe that heat can flow from a thermally insulated space to an environment with lower temperatures.

**Temperature and thermal conductivity of materials**

In this question two materials, wood and metal are considered. Students' opinions as to why wood gives the feeling that is a warmer to the touch than the metal were investigated.

The examination of students' choices shows the following main ideas:

a) Wood feels warmer than metal because metal conducts heat faster than wood does.
b) Wood feels warmer than metal because wood and metal have different temperatures.
c) Wood absorbs and stores heat
d) Metal absorbs 'cold' (small percentage).

**Ranking materials depending on their thermal conductivity**

The main ideas detected in students' explanations are:

1. Insulating materials such as fiberglass can either keep things warm or cool. These ideas are considered to be scientifically acceptable.
2. Aluminum foil does not allow heat to penetrate it.

3. Aluminum foil absorbs the 'cold'.
4. Any material when covers an object it warms it.
5. Explanations that are not backed by logic or understanding or contain scientifically invalid and logically incoherent information in a good percentage of the explanations.

**Heat transfer through mater (conduction) - Microscopic process**
In this item of the questionnaire students were asked to explain how they believe heat is transferred through a metal object to an adjacent body.

The analysis located the following explanations:

1. Use of a microscopic explanation in a very small percentage of the answers (3%) with the following ideas:
   a. Heat was transferred through the metal because the molecules become agitated (1.5%)
   b. Molecules warm those that are attached to them. This way heat is transferred (1.5%)
2. Heat passed through the metal object. Students did not give any explanation about the way heat was transferred through the metal. They see the metal object only as the medium through which the heat arrived at the adjacent to it body.
3. Answers in which the 'why' (heat was transferred) and not the 'how' is explained.
   a. Because the metal is a heat conductor.
   b. Because metal absorbs and metal stores heat.
4. Explanations that are not backed by logic or understanding or contain scientifically invalid and logically incoherent information in a good percentage of the explanations.

**Heat conduction and the role of the parameters of surface 'area' and 'thickness'**
The most important findings of the analysis of the two different questions one investigating students' ideas on the role of the area of the surface and the other on the role of the thickness were the following:
**A) For the thickness:**
Two are the main types of beliefs students have expressed:

1. The rate of heat conduction is related to the thickness of the surface through which the heat is transferred.
2. If the surface through which heat is transferred is thermally insulated the thick ness of the surface will not influence the rate of heat transfer.

**B) For the surface area:**

1. The surface area does not influence the rate of the heat conduction.
2. The rate of heat conduction is influenced by the surface area and the conductivity of the material.

In both questions there were explanations that are not backed by logic or understanding or contain scientifically invalid and logically incoherent information.

Interesting are also the side findings of the analysis in which several students believe that what is transferred is 'cold' and 'temperature'.

**Students' ability to interpret the graphical representation of thermal phenomena that are verbally described**
The analysis of this question showed that about 1/3rd of the students picked up the right graph which interprets the described phenomenon. However the most of them had difficulties in relating the represented by the graph changes in the phenomenon to the changes of all of the involved variables.

There were also several answers that are not backed by logic or understanding or contain scientifically invalid and logically incoherent information.

**2.6.3.2. THE POST-TEST ASSESSMENT:**
**The rationale for the construction of the post-test**
A sound understanding of the addressed by the TLS basic prerequisite concepts and of the mechanism of heat conduction in the different materials was expected from students. Thus, as noted earlier, a questionnaire featuring all the pre-test questions and additional new ones concerning the new issues introduced by the TLS was used. This post-test was administered at the end of the module implementation.

However, in order to track students' understanding of the microscopic mechanism of heat conduction, a 'one question test' was administered half way of the implementation of the whole TLS. In this post-test the relevant pre-test question was used right after the end of the implementation of the units concerning thermal conductivity in metals and in crystalline and amorphous materials (ceramics and polymers). In these lessons computer simulations of the microscopic mechanism were employed.

**Analysis of students' responses**

The analysis concentrated on the answers of the mid-post-test question and on the answers of selected questions of the post-test.

**Method**

The same technique as in the pre-test was employed for the analysis of the students' written documentation of the post-test questions.

**Results of Mid- Post-test**

As was described earlier, in this question, students were asked to explain how they believe heat is transferred **through** a metal object to an adjacent body. Students' understanding of the microscopic mechanism of heat conduction was anticipated.

The answers of 59 questionnaires were analyzed. In these answers 42% of the students used the microscopic explanation. In these answers the following perceptions were detected:

1. Molecules or molecules and electrons transfer heat through the metal and to the molecules of the adjacent body.

   There was no description of the process given. This type of explanation was found in four of the questionnaires (~7%) and can be characterized as 'almost scientifically acceptable'.
2. The molecules become warm and slowly transfer heat to the others.
3. Heat passes through the molecules

In the rest of the answers similar ideas to those in the pre-test answers were detected.

**Results of the Post-test**

The items selected for analyzing their answers were the one concerning thermal equilibrium of bodies and their environment (considered to be basic for students' understanding of the processes introduced by the module), the item concerning the microscopic process of heat conduction (same item as the mid-post-test and pre-test), the one concerning the role of density in distinguishing more conductive or less conductive materials grouped in the same category and the one concerning the microscopic mechanism of heat conduction in different categories of materials.

In total 69 questionnaires were analyzed and the results were shaped as follows:

**Thermal equilibrium of bodies and their environment**

In 16 of the students' answers (23%) the correct temperatures for bodies that have been in a room for sufficient time were reported. In 18.6% of them explanations consider that bodies acquire the temperature of their environment or that heat is transferred from the environment to the bodies resulting in the bodies acquisition of the environment temperature. These answers can be considered as 'scientifically acceptable'. The rest 4.4% of the explanations present the alternative conception that **temperature** is transferred from the environment to the bodies.

In 53 answers to this questionnaire item explanations similar to those identified in the pre-test were found.

**The microscopic process of heat conduction**

In 22 (32%) of the explanations of this questionnaire item reference is made to the 'building blocks' of the mater. The detected explanations can be grouped as follows:

1. Molecules collide and this is how heat is conducted or how temperature raises.

   Two explanations belong to this category (~3%). These explanations can be considered 'incomplete' since they make reference to aspects of a potentially scientifically acceptable answer but they do not give any description of the mechanism of heat transfer in the material.
2. The molecules that are close to the heat source become hot and then the other molecules become hot too.

   In this type of explanation students present the alternative conception that the change in the thermal state of the body is a result of a change in the thermal state of its molecules. This perception did not appear in the pre-test but was detected in the middle post-test.
3. Molecules are heated and collide or transfer heat to the others because metal is a heat conductor.

   These answers show that students formed the idea that what is described above is due to the thermal conductivity of the metal. Although the lessons of heat conduction of other materials such as crystalline and amorphous were implemented, it seems that the students did not form the perception that there is a basic heat transfer mechanism in all solid materials with differentiations depending on the structure of each category of them.

4. Heat passes through the molecules of the material.

   This explanation reveals the conception that heat is a substance which can flow through the 'building blocks' of the mater. This conception was not detected in the pre-test but it appeared in some of the answers of the post-test.

5. Molecules were transported to the heat source and then to the metal.

   The idea of systematic transport of mater is detected in these explanations.

6. Molecules vibrate vigorously and in this way they transfer their energy to the others and in this way heat is transported through the metal to the adjacent body.

   This type of answer can be considered as almost 'scientifically acceptable'. It was detected in only one (1) answer.

In the rest 47 answers to this questionnaire item explanations similar to those identified in the pre-test were found.

**The role of density in distinguishing more conductive or less conductive materials grouped in the same category**

Only one (1) answer to this item of the post-test refers to the density of the mater. The rest of the answers were "I don't know answers" (a large percentage), answers revealing confusion as to which category different materials belong to, and explanations that are not backed by logic or understanding or contain scientifically invalid and logically incoherent information.

**The microscopic process of heat conduction in different categories of materials**

In this question students were asked to match correct sentences given to them. The analysis showed that 40.5% of the answers were correct. In the rest of the questionnaires either there was no answer or the matching was incorrect indicating that students could not identify the correct mechanism of heat conduction for the different categories of materials.

**2.6.3.3. CONCLUDING REMARKS**

Juxtaposing the findings of the analysis of the pre-test with those of the mid-post and of the post-test we can conclude the following:

**Regarding thermal equilibrium of bodies and their environment** there is a desirable change in students' ideas. Although in a relatively low percentage (23%) it seems that these students have acquired the main idea of thermal equilibrium of bodies and their environment.

Regarding the question concerning **the process of heat conduction through mater** while only 3% of the students made reference to the 'building blocks' of mater in the pre-test, in the mid post-test 42% of them used the microscopic explanation. However, of the given explanations, only 7% can be characterized as scientifically acceptable since in the rest of the above mentioned percentage several misconceptions have been identified. Comparison with the results of the post-test analysis reveals that the percentage of the students making reference to the microscopic explanation is reduced by 10%. Within this percentage there are no scientifically acceptable explanations but only explanations that are characterized as 'incomplete'. In the rest, several misconceptions have been identified one type of which was also detected in the mid-post-test. The rest of the identified misconceptions appeared for the first time in the students' answers of this item. A possible interpretation of the above could be that while a number of students recorded the information about the role of the molecules in the heat conduction, they do not seem to have understood the mechanism with a result to either forget (reduction by 10%) or to have created misconceptions about it. This could be the result of the module itself (content, structure, processes involved) or the result of the implementation of the module in the classroom.

Regarding the findings of the analysis of the item concerning **the role of density in distinguishing more conductive or less conductive materials** grouped in the same category, the only one correct answer found and the large percentage of 'I do not know' answers lead to the conclusion that many of the students did not even record the role of the density. Also the explanations that revealed confusion as to which category different materials belong to could mean that students have confused density with other parameters or factors. These findings can be interpreted as in the previous question.

Finally, the results of the last question regarding **the microscopic process of heat conduction in**

**different categories of materials**, combined with some of the findings (e.g. confusion as to which category different materials belong to) of the analysis of the previous question (the role of density) show that 60% of the students did not acquire the appropriate knowledge of the differentiations in the heat conduction mechanism, the corresponding to differently composed and structured materials.

It is interesting to note here that, using the qualitative analysis technique described in an earlier section, we were able to detect some side findings concerning students' conceptions that can be characterized as crucial for their understanding of concepts presented in our TLS. These findings, as have been presented in previous sections of the analysis, concern the beliefs that there are entities such as 'cold' and 'temperature' that are transferred. However, these alternative conceptions continue to exist and after the implementation of the module, as the results of the analysis of the post-test indicate.

The findings of the first study gave us insights for the revision of the initially designed TLS which are presented in the next paragraph.

# 3. RESEARCH AND DEVELOPMENT OF TEACHING LEARNING SEQUENCE 2 (TLS2)

## 3.1. IMPORTANT CHANGES BETWEEN TLS1 AND TLS2

In the Local Working Group we took into account the learning outcomes reported in the previous section, as well as observational data from video taped lessons and teachers' remarks. Following a process of iterative improvement of TLS1, all these results as well as remarks by international experts were discussed and reflected upon in order to design and carry out refinements in TLS1. In the light of this multitude of data the LWG, reconsidered the aims of the TLS1 and carried out additional content analysis of the units and of resources. This procedure implied important changes in the content and structure of the TLS1 and gave rise to TLS2.

Overall, in both phases, instruction lasts about 9 hrs. However, the Units in the second phase are more focused compared to those of the first one. One change concerns the focus in the experimental field. In the second phase, the focus is more on ceramics and metals rather than on composite materials as related to the microscopic models. Macroscopic phenomena are studied in ceramics and metals so that the students are involved in guided experimental investigations and relate them to familiar experiences. Ceramics, as well as ceramics, and metals continue to be the introductory show cases of insulators and conductors. These broad categories are discussed after the introduction and treatment of the properties of ceramics and metals.

Classroom observations showed that inquiry activities were feasible and carried out smoothly by the students despite their lack of familiarization with experimentation and group work. However in introducing and carrying out inquiry activities the teachers as well their students were too much occupied in running the experiments rather than discussing science. Such observations have been referred repeatedly in the literature. The result is that students conceive inquiry as a set of dissociated activities rather than coherent constructive method for solving problem setting. Following reflection in the LWG this remark, which emerged from the observations of classroom interactions, led to a series of changes in the tasks included in the units. Also appropriate prompts for teachers were included in the guide for guiding and increasing the time and the issues for classroom discussion. Besides, it was considered appropriate that the aims of TLS could be enlarged in order to include experimental design by students in addition to involvement in carrying out an experimental activitiy. The advantages of students' involvement in experimental design are presented in section A §6 III 2.

One outcome concerned the microscopic model which has been developed for the process of heat transfer in different types of materials. Though students had been taught the microscopic model for temperature results suggested that additional special treatment should be provided by the module. Thus the unit on kinetic model of temperature was refined and included separately in the second application. The kinetic aspect of temperature is emphasized in order to facilitate students' transition towards a particulate view. Microscopic processes are treated in separate sections so that the students focus on their guided observation and explorations with the simulated models and construct links with macroscopic phenomena.

The simulated microscopic models were changed. In the following Figure the simulation screen is divided in 4 parts.

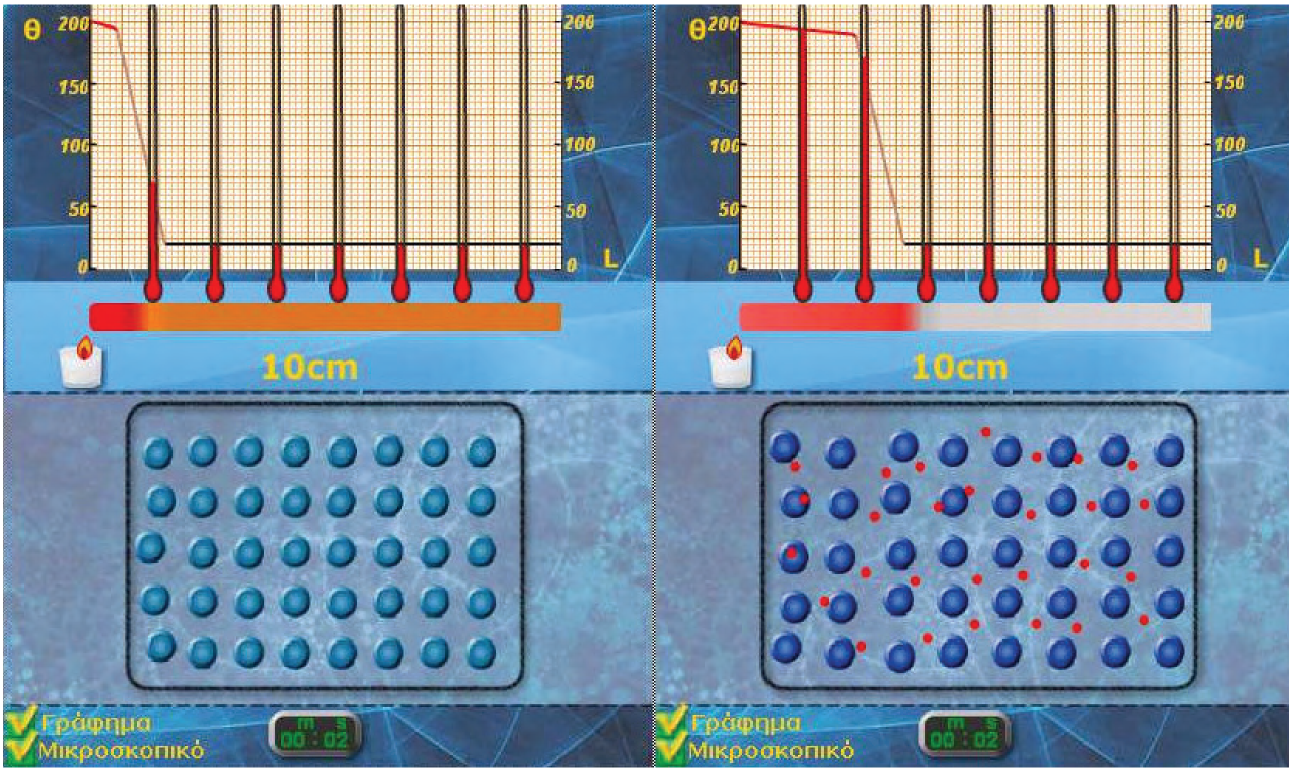



FIGURE 4: SIMULATED MICROSCOPIC MODEL FOR THE HEAT CONDUCTION IN CERAMICS AND IN METALS.

The middle part (b) shows a bar being heated. This is the "real world" frame of the simulation. The heating of the bar is depicted by the change in color, from bright red to darker-red. The color gradient is used to indicate the temperature gradient within the material while the bar is heated. A set of thermometers, in the upper part (a), and the corresponding graph, indicate the change in the temperature along the bar. The microscopic model is depicted in the middle-lower part (c). The atoms are arranged in a grid to simulate the lattice. Smaller red dots represent the electrons. The columns of atoms must not seen as a continuum but as a discontinuous, eg between the 1st and the 2nd columns students must realize that, in fact, there are millions other columns of atoms.

Thus, in our simulated models we are trying to combine 3 aspects of representation, namely, the graphical one (in top frame), the realistic (in the top middle) and the microscopic model (in the lower middle). The lowest part (d), is the frame of controls; “graph” and “microscopic” which toggle the graph and microscopic model on/off, as well as timer and the “pause” and “run” in the right most part. Simplified microscopic models have been developed for the process of heat conduction in different types of materials. The assumptions underlying these models are set in part A §7.4.3. A set of rigid balls arranged in a matrix form simulates the lattice (figure 4). A simplified lattice model is used, arranging the balls in a rectangular matrix. Ball movement (vibrational motion) is over-exaggerated for better visualization. In the amorphous material, balls are slightly misplaced from their crystalline position. This representation better describes the local ordering occurring in amorphous materials. The free electrons are depicted as small red balls for visualization purposes. The motion of the free electrons in a metallic solid is limited within the neighborhood of 8 adjacent atoms.

The simulations were re-programmed and frame (a) has been added. No thermal gradient has been considered yet; all thermometers indicate the same value, all particles were moving with the same amplitude at the end of the simulation. The addition of thermometers seems to have a great effect on students’ understanding of the thermal transfer process.

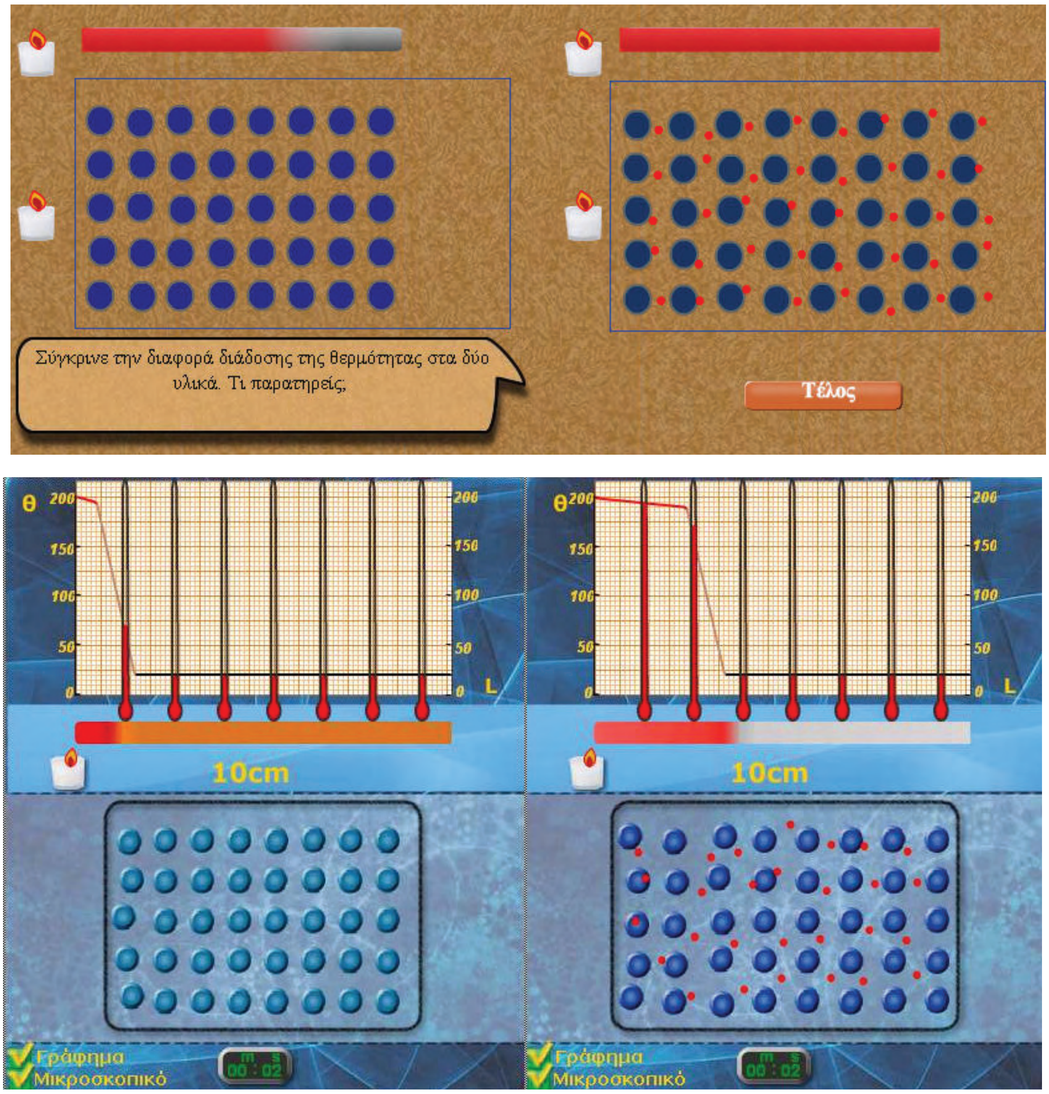



FIGURE 5: COMPARISON BETWEEN THE DESIGN OF MICROSCOPIC MODELS IN TLS1 AND TLS2

Another outcome implied that the role of density in effecting thermal conductivity in ceramics was difficult to be understood by the students so the treatments should not include calculations, as was the case in the first implementation. This resulted in changes in the Unit 5b and the density tasks.

Students work in groups following pre-designed worksheets, teachers' prompts and guidance. Taking into account the learning outcomes the students' worksheets were greatly reformed, parallel to the changes in the content of the units and in the resources (i.e. microscopic models, real and simulated experiments). The worksheets were revised in order to reduce writing and facilitate students to make proposals for experimental investigations so as to enhance their experimental skills in designing experiments. Besides students' reflection on the experimental procedures were enhanced. Special oral and written tasks were added in teaching and a whole unit was designed to facilitate student reflection on investigative activities (Unit 7).

Also, in the second phase, important additions are two lessons in which the students are involved in guided teacher-led discussion. These lessons aim at facilitating students' reflection on their knowledge and experiences with science as inquiry as well as on applications of taught knowledge in problem solving activities on how to improve the insulation of a house so that energy losses are minimized (Unit 7 and 8).

### 3.2. STRUCTURE AND CONTENT OF TLS2

Units in the second phase focused on thermal conductivity in different materials, temperature and the microcosm, thermal conductivity in ceramics and in metals, microscopic models of thermal conductivity in metals and in ceramics, size of surface and thickness as factors that affect heat transfer. Also emphasis was given to applications and metacognitive discussion on classroom activities. Besides the energy saving house is discussed extensively towards the end of the module and provides a scenario for applying taught knowledge by students who are prompted are prompted to make suggestions for preventing heat loss.

An overview of the suggested structure of the module is provided below. All units are expected to take place in one teaching hour except Units 5 and 6 which take place in two teaching hours.

TABLE 2: CONTENT AND STRUCTURE OF TLS2

| | |
|---|---|
| **UNIT 1** | Students study thermal interaction between quantities of water having the same temperature in cups made of different materials, during their cooling down and rank the materials used, according to their thermal conductivity. |
| **UNIT 2** | Students explore microscopic simulated models for temperature in ceramics and metals. |
| **UNIT 3** | Students explore the role of the oscillation of particles of the lattice in thermal conduction in ceramics and in metals as well as the role of free electrons in thermal conduction in metals and interpret thermal conduction. |
| **UNIT 4** | Students study experimental techniques such as use of thermographic paper to detect heat conduction and rank metallic rods according to their thermal conductivity. |
| **UNIT 5** | Students study conductivity in ceramics and the role of density of materials in effecting heat conduction in both microscopic and macroscopic aspects. |
| **UNIT 6** | Students carry out an investigations in simulated lab on how the size of the thickness of walls of a vessel as well as their surface area affect thermal conduction in both heating and cooling situations. |
| **UNIT 7** | Students discuss and reflect on taught knowledge and applications and about synthetic materials. |
| **UNIT 8** | Students apply their knowledge and skills to study thermal loss in an energy saving house. |

## 3.3. EMPIRICAL STUDY OF TLS2: IMPLEMENTATION AND DATA COLLECTION AND RESULTS

### 3.3.1. CONTEXT

The revised TLS was implemented in the fall semester of the year 2008 and the beginning of 2009. Implementation was carried out in two schools different than those in which TLS1 was first implemented. These were a private school in the city of Thessaloniki and a public school in a suburban area of Thessaloniki.

### 3.3.2. DATA COLLECTION

In this section we report on the study of students' conceptual achievements. Data on students' prior ideas and learning outcomes were collected by administering questionnaires ahead of the module implementation and at the end of it.

### 3.3.3. INVESTIGATION OF STUDENTS' PRIOR IDEAS:

**The instrument**

A questionnaire consisting of 6 questions was used. Questions were events and experiences from every day life and were mostly of 'multiple choice' (see selected items in Appendix). Students were asked to give written documentation of their choices.

**The rationale for the construction of the pre-test**

Taking into consideration that the the main objective of this TLS is to introduce students into the thermal properties of materials and more specifically to the thermal conductivity of materials (how well do materials of different categories transmit heat and what is the process of heat conduction) as well as to inquiry teaching a new test was developed. Students' ideas prior to the introduction of the TLS were investigated in the following issues:

- Thermal equilibrium of bodies and their environment.
- Microscopic explanation of thermal conduction through matter.
- The role of the environment in the insulation procedures.
- Thermal conductivity of different materials
- Ranking materials depending on their thermal conductivity.

### 3.3.4.THE POST-TEST ASSESSMENT:

For comparative analysis purposes the post-test questionnaire included the same as the pre-test questions and additional ones for testing students' learning outcomes of the new issues introduced by the TLS. The post-test questionnaire consisted of 10 questions (see selected items in Appendix).

**Analysis of students' responses to the post-test**
**Method**

Qualitative analysis of the students' written documentation was employed. The procedure used identification of regularities in the first stage followed by a constant comparative technique.

**Results**

In what follows results of the analysis of representative questions are presented:

**Thermal equilibrium of bodies and their environment:**

Twenty four (24) questionnaires were analyzed. Students' answers were organized in five different categories:

1: 'Scientific answer' (13 answers): Answers in this category are considered to be 'scientifically acceptable'.

2: 'The correct answer has been chosen but the explanations are not backed by logic or understanding or contain scientifically invalid and logically incoherent information' (4 answers).

3: 'The wrong answer has been chosen and the explanations are not backed by logic or understanding or contain scientifically invalid and logically incoherent information' (3 answers).

4: 'No answer' (1 question).

5: 'The correct answer has been chosen without explanation' (3 answers).

**Ranking materials depending on their thermal conductivity - conductivity of different materials:**

Twenty four (24) questionnaires were analyzed. Students' answers were organized in 3 different categories:

1: 'Scientific answer' (14 answers): Answers in this category are considered to be 'scientifically acceptable'.

2: 'Three type alternative answers' (8 answers): Subcategories:

S1: Correct choice of one of the materials and the explanation is considered scientific.

S2: Correct choice of one of the materials but the explanation is alternative.

S3: Wrong both choices of the materials and the explanations are not backed by logic.

3: 'Either no choice has been made or explanation is not given' (2 answers).

**Microscopic explanation of heat conduction and conductivity of different materials:**
Twenty four (24) questionnaires were analyzed. Students' answers were organized in 2 different categories:

1. 'Metal is a good heat conductor' (8 answers): In this category were organized answers which attribute the phenomenon to the good conductivity of the material without making any reference to the microscopic explanation.
2. 'Use of microscopic explanation' (16 answers). This category is divided in two subcategories:
   a) 'Scientific answers' (6 answers). Answers organized in this category attribute heat conduction through metal to the movement of the electrons.
   b) 'Partially scientific' (10 answers). These answers attribute the phenomenon to the vibration of the molecules or to the 'building blocs' of mater in general.

### 3.3.5. DISCUSSION AND CONCLUSION

The findings of the analysis of the pre-test were juxtaposed with those of the post-test and integrated results were recorded. Results were organized in relation to the following main issues:

- Thermal equilibrium of bodies and their environment.
- Conductivity of different materials.
- Ranking materials depending on their thermal conductivity.
- Microscopic explanation of thermal conduction through matter.

The comparative analysis showed the following trends in students' ideas and explanations:

**Thermal equilibrium of bodies and their environment:**
While in the pre-test approximately 4% of the students' answers were considered scientifically acceptable, there was a desirable change in their ideas which was identified in 54% of them. Students seem to have acquired the main idea of thermal equilibrium of bodies and their environment.

**Conductivity of different materials:**
For the exploration of students' understanding of this issue student ideas were tested for two different materials: metal and plastic. Results indicate that students (64.5%) distinguish metal as a good conductor of heat and plastic as a bad one. It is interesting to note that a few of these students were able to indicate that although plastic is a bad heat conductor, a plastic object being in contact with a heat source for a long period of time, will, to a degree, conduct heat.

**Ranking materials depending on their thermal conductivity:**
To explore students' ideas three types of materials were used: glass, metal and plastic. In the pre-test, 21 students were assessed due to absences. Of these, 28.5% gave answers that can be characterized "scientific" while in the rest confusion and inconsistency in their ideas regarding materials conductivity was detected. In the post-test 24 students were assessed. The percentage of the answers given by these students that can be characterized as scientific rose to 58%, while in the rest, ideas similar to those detected in the pre-test were found.

**Microscopic explanation of thermal conduction through matter:**
In the pre-test, 4% of the students made reference to the 'building blocks' of matter as a mechanism for heat conduction. However, these students attributed thermal conduction to the "systematic transfer of hot molecules" within the material. In the post-test almost 33% attributed heat conduction within the material (metal) to its good thermal conductivity. 63% of the assessed students gave explanations in which they used microscopic processes. Within this percentage 21% gave answers that can be considered "scientific" attributing heat conduction through metals to the movement of the electrons, while of the rest, 42% can be characterized as "partially scientific" since they attributed the phenomenon to the vibration of

molecules or to the vibration of the 'building blocks' of matter in general, making no specific reference to electrons

Juxtaposing the results of the initial TLS with those of the study of the second one (TLS2) it can be seen that there is a noticeable improvement of students' conceptual gains in the two issues 'Thermal equilibrium' and 'Microscopic explanation of thermal conduction' which were tested in both the study of the TLS1 and that of the TLS2. Regarding the new issues ('Conductivity of different materials' and 'Ranking materials depending on their thermal conductivity') in which students' ideas were tested in the study of TLS2, juxtaposition of the results of the investigation of students' initial ideas on these issues and of those of the post-instructional assessment shows a noticeable increase in the percentage of students' scientifically acceptable ideas. However, taking into consideration that a sound understanding of the above concepts and process is expected from students, and targeting a TLS with a final structure approaching a more integrated inquiry oriented teaching approach, the findings point to specific revisions in the structure and content of the units.

# 4. RESEARCH AND DEVELOPMENT IN TEACHING LEARNING SEQUENCE 3 (TLS3)

## 4.1. IMPORTANT CHANGES BETWEEN TLS2 AND TLS3

The Local Working Group took into account the learning outcomes reported in the previous section as well as observational data from video taped lessons and teachers' remarks. Such data showed that students carried out the tasks more smoothly than in TLS1 given the restructuring of units, reduction in cognitive load and time saving by reducing written requirements within each unit. Overall they managed to cope with the tasks though in certain cases both the teacher and the students rushed in order to fulfill written requirements. The students did not only run experimental investigations but they were actively involved in planning experiments and enjoyed group work. In classroom discussions, they mentioned that were excited by active involvement in experimentation, exchanging of ideas within their group and planning on how to proceed in certain tasks.

Following a process of iterative improvement from TLS1 to TLS2 and TLS3 all these results as well as remarks by international experts were discussed and reflected upon by the LWG, in order to design and carry out refinements in TLS2. In the light of these multitude of data the LWG reconsidered the aims of the TLS2, carried out additional content analysis of the units and of resources. One main decision concerned modeling. Following the improvement of students' involvement in handling microscopic models and the relevant learning results the LWG decided to extend the aims of TLS2 and pursue not only learning with models but also learning about scientific models which is an essential aspect of scientific inquiry.

A second main decision was to keep the expected overall duration of the units up to nine hours and make some minor changes in the content which appear below. Within units the written requirements were reduced even more in order to save time for discussion and reflection. Besides it was decided to enrich further the units by extension activities some of which could be carried out at home and facilitate even further metacognition by students on the nature of classroom activities. Some of these activities would involve students in web based searching about applications.

Specific changes are summarized in the final Table in Part E § 5.

With regard to resources, simulations were re-programmed, and all texts and messages that appear are taken from an external editable txt file. This way texts and messages in the simulation are easily translated into another language (eg. English, Italian, etc.). This Phase was taken during the transfer-process of our module into Italian Schools. In addition the simulations were reprogrammed (again) and all data shown are taken from external editable dat file. In this way, the contents of the simulation (graph, time evolution of temperature, material) can be externally edited. Also, frame (d), the control frame was added. Thermal gradient has been considered; all thermometers do not indicate the same value, all particles are not oscillating with the same amplitude, at the end of the simulation. The color in the "world" frame changes from dark red to bright red as heat propagates into the material. The addition of the "control frame" offers flexibility to teaching approaches (eg. one teacher may want to start with the macroscopic model, another may want to start from the microscopic description, etc).

### 4.2. STRUCTURE AND CONTENT OF TLS3

The above procedure implied a certain changes in the content and structure of the TLS2 and gave rise to TLS3.

TABLE 3: CONTENT AND STRUCTURE OF TLS3

| | |
|---|---|
| **UNIT 1** | Students study experimentally thermal interaction between quantities of water having the same temperature in cups made of different materials, during their cooling down and rank the materials used, according to their thermal conductivity. Reflect about their experimental activities. |
| **UNIT 2** | Students explore microscopic simulated models for temperature in ceramics and metals, compare different representations of models, search in the web for other representations of microscopic models and reflect on the function of simulation for understanding heat transfer. |
| **UNIT 3** | Students explore the role of the oscillation of particles of the lattice in heat conduction in ceramics and in metals as well as the role of movement of free electrons in conduction in metals. They use models to visualize and interpret heat conduction and reflect and learn about the function and use of models in science. |
| **UNIT 4** | Students study experimental techniques such as use of thermographic paper to detect heat conduction, design experimental investigations, are involved in hands on experimentation and rank metallic rods according to their thermal conductivity. The use of conductors in house and everyday situations is discussed. |
| **UNIT 5a** | Students study conductivity in ceramics and the role of density of materials in effecting heat conduction. They are engaged in experimental design and discus the use of insulating material in everyday situations. |
| **UNIT 5b** | Students continue to study thermal conductivity in ceramics, design an experimental procedure to investigate the relationship between density and conductivity in ceramic materials and choose appropriate insulating material for a specific purpose. |
| **UNIT 6** | Students carry out an investigations in virtual lab on how the size of the thickness of walls of a vessel affect conduction, discuss the role of surface area. They reflect on experimental design for investigating several factors affecting conduction. |
| **UNIT 7** | Students discuss and reflect on taught knowledge and aspects of inquiry, discuss several insulating and conducting materials are acquainted with synthetic materials and applications in house. |
| **UNIT 8** | Students apply their knowledge and skills to study and reduce thermal loss in an energy saving house. |

## 4.3. EMPIRICAL STUDY OF TLS3: IMPLEMENTATION AND DATA COLLECTION AND RESULTS

### 4.3.1. CONTEXT

The final version of the TLS was implemented during the fall semester of the year 2009. Implementation was carried out in one school: A private school in the city of Thessaloniki, and in a class of 25 students aged 14 years.

### 4.3.2. DATA COLLECTION

Data on students' prior ideas and learning outcomes were collected by administering questionnaires ahead of the module implementation and at the end of it.

### 4.3.3. INVESTIGATION OF STUDENTS' PRIOR IDEAS AND POST INSTRUCTIONAL ASSESSMENT AND THEIR CONCEPTUAL EVOLUTION

To investigate students' preconception a questionnaire consisting of 6 items was used (see part D §2.1 and §2.2 of the present document). The items concerned mostly events and experiences from every day life. A number of them were of multiple choice questions in which the students were asked to give written documentation of their choices. For comparative study purposes, the post-test questionnaire included the same as the pre-test items and additional ones specifically formed for testing students' learning outcomes on new issues introduced by the TLS. Thus the post-test questionnaire consisted of 10 questions (see part D §2.3 and §2.4 of the present document).

### 4.3.4. RESULTS ON CONCEPTUAL KNOWLEDGE

In what follows we present results of the analysis of the pre and post questionnaires on selected issues introduced by the final version of our TLS and the overall outcomes of the implementation of it:

Regarding thermal equilibrium of bodies and their environment -Question 1-, while in the pre-test 8% of the students' answers were characterized as scientifically acceptable, in the post-test the percentage of students who gave scientifically acceptable answers increased to 52%. The students correctly predicted the bodies' temperatures and justified their answers referring to **thermal equilibrium of the bodies' and their environment.**

Regarding **conductivity of different materials** - Question 3- in the pre-test 36% of the students chose the correct answer (metal conducts heat faster than wood). In the post-test the percentage rose to 68%.

In **ranking materials depending on their thermal conductivity** -Question 5- in part A, in the pre-test, 48% of the students chose the correct answer and justified it correctly. In the post-test this percentage rose to 88%. Of these a very small number (two students), in their justifications, expressed some ideas that can be characterized as alternative such as that 'heat is absorbed' by the material. In part B, in the pre-test 40% of the students chose the correct answer and all but one justified their choice correctly. In the post-test the percentage of the students who chose the correct answer rose to 92%. All but two of their explanations were scientifically acceptable. In those characterized as alternative, the ideas that 'metal absorbs cold' and the idea that 'temperature is transferred' were found.

Regarding the role of **the environment in the insulation procedure**s –Question 2- in the pre-test 28% of the students gave correct answers and correctly justified them. In the post-test, 52% of the students' answers were characterized correct. The students explained the reduction of the temperature of the thermos's content as the result of the heat loss from the insulated walls of the thermos.

Regarding **the microscopic explanation of thermal conduction through matter** - part B of Question 6- while in the pre-test 8% of the students formulated scientifically acceptable interpretations of the phenomenon, in the post-test the percentage of these students rose to 92%.

Regarding **students' understanding of factors that make some materials more conductive than others** -Question 9- all of them, selected the correct model representing the structure of the most conductive material. In their explanations 92% of them expressed scientifically acceptable ideas. Two students, in their explanations, expressed alternative ideas such as "the electrons are good heat conductors".

### 4.3.5. INVESTIGATION OF STUDENTS' PRIOR IDEAS AND POST INSTRUCTIONAL ASSESSMENT ABOUT MODELS

The first and the second question of the pre and the post-test of models refer to the nature of models, that means that through these questions we investigate the students' ideas about what is a model, its' definition. The exact questions are shown below:

1) What do you think that a scientific model represent? Justify your answer and give two examples.
2) Do you think that a scientific model should represent the reality exactly as it is or not? Justify your answer.

**Pre-test**

The majority of students (17 from 25) held ideas about the nature of models in the pre-test that were differentiated from those posed from scientists and their ideas were classified in level 1. These students consider that the model represents exactly the real world or a phenomenon as it is. Students' answers, also, show that there is no distinction between the model and the real world. Representative answers are:

*"A scientific model represents the reality, a phenomenon. The model has to represent the reality as it is because it gives to the user useful information"*
or
*«The scientific model represents physical things, like the map and the pictures that compare an organism in Biology".*

Five (5) students had ideas that were classified in level 2 as they referred that the model is a way to understand a phenomenon, even though they considered that the model should represent the reality exactly as it is. Representative answers are:

*"A model helps us to derive conclusions about the phenomena that we are interested in"*
or
*"A scientific model is the representation of an epistemic fact, like a picture that shows the molecular structure of the hydrogen or a video that shows us how big bang occurred".*

The ideas of 3 students were classified in level 3. These students considered that the model is a representation of a theory and shouldn't represent the reality as it is. A representative answer is:

*"A scientific model explains a theory. It shouldn't represent the exact reality".*

**Post-test**

The majority of students in the post-test had ideas about the nature of models that were classified in level 2. These students distinguished the model from the real world. Only 5 from the 25 students had ideas that were classified in level 1. These 5 students didn't distinguish the model from the real world. Representative answers are:

*"A scientific model represents the reality in a smaller scale"*
or
*"The scientific model represents physical things like the map and the figures that compare an organism in Biology".*

The majority of students (15 from the 25) had ideas that were classified in level 2 as they considered that the model is a way to understand a phenomenon, while simultaneously they distinguished the model from the reality. Representative answers are:

*"A scientific model helps us to understand a phenomenon or to observe a thing in the better possible conditions. The scientific model not necessarily represents the reality as it could be a simulation"*
or
*"A scientific simplifies a phenomenon in order to be easily and better understood».*

Five, (5) students had ideas about the nature of models that were classified in level 3 as they considered that the scientific model represents an idea/theory or that a model represents the imagination of the scientist, while they simultaneously they consider that the model shouldn't represent exactly as it is the reality. Representative answers are:

*"The scientific model represents an idea/theory. We use the model in order to explain the phenomenon that we observe and to predict it before the observation of it. The model shouldn't represent the reality exactly as it is because comprises the theory/idea of how we imagine to be the things that we can't observe in order to predict and interpret them"*
or
*"A scientific model represents how scientists imagine the inner part of the matter. It doesn't show always the reality, as we don't know the validity of all the models".*
*From the analysis of the pre and the post-test comes*

*out that the implementation of the teaching sequence had particular effect to the distinction between the model and the real world and that the model shouldn't represent the reality exactly as it is.*

The third and the fourth question refer to the purpose of the model, which means that through these questions we investigate the students' ideas about the use of models and if they consider that the model is a powerful research tool. The exact questions are shown below:

3) What do you think is the purpose of a scientific model? For what reason can the model be used?
4) Do you think that a scientific model is a powerful research tool or not? Justify your answer by referring two reasons for that.

**Pre-test**

The ideas, about the purpose of models, of 11 students in the pre-test were differentiated from those posed from scientists and their ideas were classified in level 1. Students' answers that were classified in level 1 referred that the purpose of the model is to help and to facilitate the realization or the comparison of some experiments. Representative answers are:

*"The purpose of the model is to help us realize some experiments, which help us to ascertain if our initial hypothesis is right or wrong and so comprise a powerful research tool"*
or
*"The model is a powerful research tool because helps the progress of the science and is used in order to compare some things between them through some observations"*
or
*"The scientific model can be used in order to simplify things and comprises a powerful research tool because when a phenomenon is in front of you, you can study it better".*

From the analysis of these students' answers in these two questions of the questionnaire we conclude that these students don't distinguish the model from the experiment, referring that models are objects that help us through experiments to derive conclusions. Whereas they consider correctly that models comprise powerful research tools, their answers are classified in level 1 because in their mind when they refer the model they mean the experiment. One student considered that the model is not a powerful research tool.

Nine (9) from 25 students had ideas that were classified in level 2 as they referred that the purpose of the model is to help us understand and interpret the phenomena, without however, giving the possibility of new discoveries. Seven (7) of the students considered the model to be a powerful research tool and representative answers are:

*"The purpose of the scientific model is to help us interpret a phenomenon and comprises a powerful research tool"*
or
*"The model helps us to see something that is not observable with the eye and is a powerful research tool because it helps us to understand the phenomena".*

Two (2) of the students that considered that the purpose of the model is to help the understanding of the phenomena they referred to models as powerful research tools. A representative answer is:

*"The scientific model helps us to understand the theories of Physics and other Sciences, without being however a powerful research tool because it doesn't help us to discover new theories".*

The ideas of 5 students were classified in level 3 as they considered the model to be a powerful research tool that is used for the progress of the knowledge, for new discoveries, for the development of new theories. Representative answers are:

*"A scientific model can be used in many ways. Firstly, it can be used for the progress of the knowledge. It is also the basis for the development of other theories or models and for that reasons it is a powerful research tool"*
or
*"The scientific model is used in order the scientists to express their opinion and to support and present it"*
or
*"The scientific model is a powerful research tool because it helps us to develop new theories that will give answers to unanswered questions".*

**Post-test**

The ideas about the purpose of models of the majority of students (17 from the 25) in the post-test were classified in level 2, as they considered the purpose of the model to be its' contribution in the understanding of the phenomena. Representative answers are:

*"The scientific model is a powerful research tool because help us understand better the phenomena"*

or

*"The purpose of the scientific model is to present us some things in such a way that we can understand them and for that reason it is a powerful research tool".*

Six (6) of the 17 students considered that the purpose of the model is to help us to understand the phenomena but they referred to models as not to be powerful research tools. Representative answers are:

*"The scientific model is not a powerful research tool because it help us understand a concept but it doesn't help us discover new theories"*

or

*"The scientific model doesn't comprise a powerful research tool because even though helps us to understand the phenomena, it doesn't help us make new discoveries. For example in the microcosm the model is based on our knowledge until today".*

After the teaching sequence, 8 students had ideas that were classified in level 3 referring to the explanatory and predictive use of models, while they recognized the contribution of models to the development of new theories and to the evolution of Sciences:

*"The scientific model is a powerful research tool because helps us interpret and predict the phenomena"*

or

*"I think that a scientific model is a powerful research tool because for example many scientists need to be based in other theories in order to develop their theories"*

or

*"The purpose of the scientific model is to represent already substantial discoveries of scientists about a phenomenon and to help to new discoveries".*

### 4.3.6. DISCUSSION RESULTS ABOUT CONCEPTS AND MODELS

The findings of the analysis of the 4 last questions of the post-instructional questionnaire and of the comparative study of those tested in pre and post level reveal the following: After the instructional intervention, a large percentage of students could give an explicit definition of what a good heat conductor is and what is an insulator [question 8α (84%) και 8β (68%)]. A large percentage of students seem to have understood well two things: a) what is that makes metals better conductors than other materials and which is the microscopic mechanism of heat conduction [questions6 (92%) και 9 (92%)], while the percentage of the students who expressed alternative conceptions in the justification of their answers was very small. High was also the percentage of students who, after the intervention, can well distinguish which materials are more, or less heat conductive [questions 3 (68%) και 5 (88% και 92%)]. Again the percentage of the students who expressed alternative conceptions in the justification of their answers was very small. The results show that students, although after the intervention the percentages of their scientifically acceptable answers significantly increased, face more difficulties in: a) comprehending thermal equilibrium of the bodies and their environment [questions 1 (52%)] and b) in comprehending that heat is conducted slowly through insulators [questions 2 (52%) και 7 (52%)]. Another issue in which students seem to have found a bit more difficult to comprehend is that insulators do not provide heat to the bodies they surround but only prevent heat from 'escaping' in the environment keeping thus these bodies' temperature from decreasing for a an amount of time [question 4 (48%)]. Overall, the results demonstrate that, after the implementation of the TLS, students' learning seems to have significantly improved in he most of the cognitive issues targeted by the module.

Concerning the students' awareness on models, the results from the TLS show that the students had also significant progress. Specifically, concerning the nature of models after the TLS, the majority of students (15 from 25, 60%), changed their ideas from level 1 to level 2 as they considered that the model is a way to understand a phenomenon and not a replica of a phenomenon, while 5 from the 25 students (20%) managed to acquire ideas of level 3 about the nature of models referring that models represent an idea, a theory or the imagination of a scientist. One of the most significant findings is that despite the level 2 or 3 that students have acquired after the instructional intervention, a high percentage of students (20 from 25, 80%) were able to distinguish clearly the model from the experiment.

Regarding the students' ideas about the purpose of models, the results show that after the implementation of the TLS the students' ideas were divided in levels 2 and 3, while before the TLS 11 from the 25 students (44%) held ideas about the purpose of models on level 1. Specifically, after the TLS the majority of students (17 from 25, 68%) recognized the explanatory use of models and 8 from the 25 students (32%) had ideas that were classified in level 3 referring not only to the explanatory but also to the predictive use of models, while they recognized the contribution of models to the development of new theories.

## 5. ITERATIVE CHANGES IN TLS1, TLS2, TLS3

Research and development in line with current trends in science education have been applied for developing an innovative ICT based inquiry oriented TLS aiming at providing compulsory education students with a comprehensive treatment of thermal conductivity in materials as well as at introducing them to inquiry in science. From the initial application it appeared that teaching of the TLS as an extensive module to the current lower secondary curriculum in Greece has been feasible. This was important as a fist modest step to apply innovative inquiry teaching to a traditional context since both teachers and students were familiar with teaching of science as transfer of knowledge. Taking into consideration that a sound understanding of concepts and process was expected from students, empirical findings pointed out that specific revisions should be made leading to a process of iterative improvement of TLS1 and adaptation to students' capabilities. Following the feasibility of TLS1 the initial aims were progressively broadened in order to include other important aspects of inquiry such as experimental design and learning about models.

In addition to changes in the aims between TLS1 and TLS3 there were made significant changes in the content, the resources used, the experimental application field, the organization of the module and teaching strategy. These changes can be summarized in the following Table.

TABLE 4. SUMMARY OF IMPORTANT CHANGES THAT TOOK PLACE IN THE SUCCESSIVE TLSs.

| 1st TLS | 2nd TLS | 3rd TLS |
|---|---|---|
| **1. AIMS AND OBJECTIVES** | | |
| Students' conceptual understanding of thermal conductivity and the factors affecting it. | Unchanged | Unchanged |
| Acquisition of skills in carrying out guided investigations. | Emphasis on students' skills on experimental design. | Unchanged |
| Model based explanations of conduction in various materials. | Unchanged | Students' understanding about models and modeling. |

| 1st TLS | 2nd TLS | 3rd TLS |
|---|---|---|
| **1. AIMS AND OBJECTIVES** | | |
| Enhance student interest and attitudes towards Sciences. | Unchanged | Unchanged |
| **2. CONCEPTS/CONTENT** | | |
| Kinetic model of Temperature was taken for granted due to teaching before the TLS.<br>Results showed student difficulties in handling this model. | Kinetic model of Temperature was treated in a separate unit before engaging in the process of conduction. | Unchanged |
| Density as a factor affecting conductivity in ceramics was treated with microscopic simulations.<br>Results showed this was ineffective. | Density as a factor affecting thermal conductivity in ceramics was treated macroscopically. | Density as a factor affecting thermal conductivity in ceramics was treated macroscopically, as opposed in metals. |
| | The focus was more on ceramics and metals and the relevant models for conduction. | Unchanged |
| Microscopic models of composite materials were treated.<br>Results showed this was cognitively demanding. | Composite materials were treated mainly macroscopically. | Unchanged |
| **3. FIELD OF EXPERIMENTAL APPLICATION** | | |
| Metals, ceramics, amorphous materials, alloys and composite materials were treated.<br>Results showed this created work overload. | The study of materials was reduced to metals, ceramics and composite materials. | The study was limited in metals and ceramics |
| Everyday applications were studied extensively. | Unchanged | Unchanged |
| | A scenario about thermal insulating of a house and energy loss was added. | A scenario about insulating of a house and energy loss was discussed more through extension activities carried out as homework. |

| 1st TLS | 2nd TLS | 3rd TLS |
|---|---|---|
| **4. RESOURCES** | | |
| Some characteristics in the interface of the simulations were misleading to students. | Simulations were improved according to students' and teacher remarks. Virtual thermometers and graphs were added. | Generally unchanged. One virtual experiment by Thermolab was used as an option for investigating the effect of thickness. |
| **5. ORGANIZATION** | | |
| Both macro and micro treatment of conduction were linked in each unit for various materials.<br>Results showed student difficulties in understanding and distinguishing these models. | Units were more focused.<br>Microscopic models on ceramics and metals were treated and compared in one unit.<br>Thermal conduction in ceramics and metals were treated and compared macroscopically and interpreted by these models. | Questions and statements in the Units were further refined. |
| | Students were asked to discuss and respond orally to certain tasks in each unit instead of providing written answers in order to reduce work load and save time. | Even more refinement of the units in this respect. Provision of extension activities for teachers and students some of which could be done as homework. |
| | | Experimental treatment of the effect of thickness on conduction by virtual experiment and study of surface by applications. |
| | | Addition of activities providing guided use of web based tasks. |
| **6. TEACHING STRATEGY** | | |
| Structured experimental investigation and model use activities were emphasized.<br>Results showed that at times students and teachers emphasized doing science to cope with tasks rather than talking science. | Unit length was reduced.<br>Discussion was emphasized and reflection on the experimental procedures was facilitated by special tasks. | More emphasis on discussion, experimental planning and reflection on tasks carried out through appropriate tasks. |
| Students carried investigations but did not plan experiments. | Worksheets were revised in order to facilitate student planning of an experiment. | Worksheets were revised even more in order to facilitate student experimental planning and understand about modeling. |
| | Two lessons were added involving students in teacher-led reflective discussion and problem solving activities for improving insulation in a house. | Even more discussion, reflection, metacognitive phase. |

Empirical findings presented in the present section E focused on aspects of conceptual aims and modeling. Examining the evolution of students' conceptual understanding from the initial TLS1 to TLS3 we can argue that there was a considerable improvement in the ideas of students in all of the issues treated by the Teaching Learning Sequences. It is important to note that in the most difficult for the students to understand issues, those of 'Thermal equilibrium' and 'The microscopic explanation of heat conduction', their conceptual understanding improved remarkably. Especially in the last one in which their ideas evolved from the point of not referring at all to the microscopic world in their explanations of the phenomenon to that of the majority of them providing explanations which when examined in comparison with aspects shown in the computer simulations studied by them, indicated significant similarities between their explanations and the events represented in the simulations. Apart from conceptual understanding considerable was also the student's understanding of models, as indicated by the results presented here. Students, although they had difficulties to understand that models represent an idea or a theory, they distinguished the model from the experiment and they understood the explanatory use of the models. It is also interesting to note that some of them even managed to also recognize the predictive use of the models.

## APPENDIX

Selected items from the TLS1 study tests

**PRE-TEST**

- During winter you visit your country house in the mountains. The temperature inside the house is 6o C. There are different items left in the house. Can you predict what will the temperature of the following objects be? A woolen sweater, a metal saucepan, A wooden table. Why do you think these items will have the specific temperature?

- The top of a table is wooden and its legs are metal. When you touch the wooden top with one of your hands and one of the legs with the other, you will feel that the top is warmer than the leg. This happens because:

  Wood absorbs and stores heat while the metal doesn't.

  Metal and wood have different temperatures

  The metal conducts heat faster than wood does

  Wood absorbs the cold.

  The metal absorbs the cold.

  Choose those answers that you think are correct and justify your choice.

- A friend of yours uses a metal spoon to stir the food while cooking. After a while he feels his fingers burning. How do you think heat was transferred through the metal to the fingers of your friend?

- One of two adjacent stores has its façade made of glass and the other part of it. If on a cold day the heating system breaks down in which of the stores the staff will feel cold sooner? Justify your answer.

**POST-TEST**

- A thermometer shows the actual temperature of the human body when:1) The body's temperature is such that allows the transfer of heat, 2) Thermometer and the human body have the same temperature, 3) Heat stops flowing from the body to the thermometer, 4) We can not know, it depends on the type of the thermometer. Choose the correct answer and justify your choice.

- On a snowy day three friends made a snowman. Another friend was coming later and they had decided to show it to him. However, the sun came out and the temperature started rising. Thus the friends had to decide how to keep the snowman from melting. Each of the friends expressed a different opinion on how to make it plausible. a) Cover it, said one of them, with your ski jacket that has a composite material, fiberglass. This will keep it cold and will prevent him from melting, b) No, said the other one, the ski jacket will warm it up and will make it melt, cover it with aluminum foil, c) Whatever you cover it with will not make any difference.

  Who do you think was right? Justify your answer.

- Two submarines that have the same size are floating in the same depth in a cold see. The thickness of their walls is bigger in one of them. The walls are thermally insulated. If the heating system breaks down the crew will feel cold sooner: 1) In the one that has thinner walls, 2) In the one that has thicker walls, 3) For thermally insulated walls thickness doesn't play a role. Choose the correct answer and justify your choice.

Selected items from the TLS2 study tests

**PRE-TEST**

- During winter you visit your country house in the mountains. The temperature inside the house is 6o C. There are different items left in the house. Can you predict what will the temperature of the following objects be? A woolen sweater, A metal saucepan, A wooden table. Why do you think these items will have the specific temperature?

- The top of a table is wooden and its legs are metal. When you touch the wooden top with one of your hands and one of the legs with the other, you will feel that the top is warmer than the leg. This happens because:

  Wood absorbs and stores heat while the metal doesn't.

  Metal and wood have different temperatures

  The metal conducts heat faster than wood does

  Wood absorbs the cold.

  The metal absorbs the cold.

  Choose those answers that you think are correct. and justify your choice.

- A cold winter day, you and two of your friends went to the school café to drink hot chocolate. The hot chocolate was served to you in cups made of three different materials-plastic, metal and glass. All the drinks had the same temperature the time they were served to you. If you were to pick up a cup first, which of the three cups-glass, metal or plastic-would you choose in order to make sure that your fingers wouldn't be burned? Give a brief explanation of your choice. In which of the cups you believe that the chocolate will cool down faster? Give a brief explanation of your opinion.

- A friend of yours uses a metal spoon to stir the food while cooking. After a while he feels his fingers burning. How do you think heat was transferred through the metal to the fingers of your friend?

## POST-TEST

- You will have seen that on electric water heater there is a little red light which, when it goes it signals that the heater is using electricity. When the water reaches the desirable temperature the light goes off. However, although as you know the water heater is a well insulated apparatus, you will have seen that the little light, every so often, goes on even when the hot water is not consumed. Can you explain why does this happen?

- A cold winter day, you and two of your friends went to the school café to drink hot chocolate. The hot chocolate was served to you in cups made of three different materials-plastic, metal and glass. All the drinks had the same temperature the time they were served to you. If you were to pick up a cup first, which of the three cups-glass, metal or plastic-would you choose in order to make sure that your fingers wouldn't be burned?

  Give a brief explanation of your choice:

- When you hold a metal tong over the barbeque or the fire place, after a while, you will feel your fingers burning. How you think this happens? Can you give a microscopic explanation to this phenomenon?

- If you stir the hot food while cooking with a plastic spoon do you think you will feel your fingers burning? Justify your answer.

- In the following two figures the microscopic structure of materials belonging to two different categories is shown. Can you tell which of these materials conducts heat faster? Justify your answer.

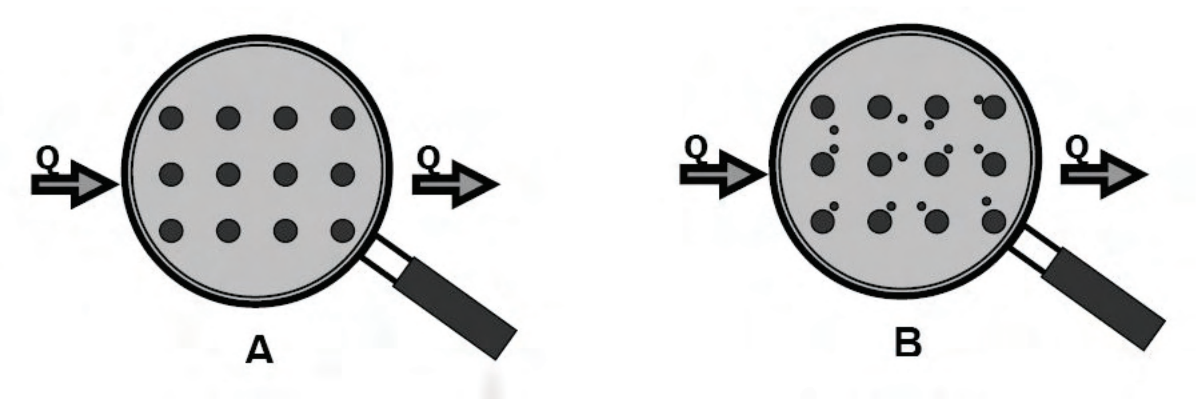



FIG. 6

# REFERENCES

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Abd-El-Khalick, F., BouJaoude, S., Duschl, R., Lederman, N.G., Mamlok - Naaman, R., Hofstein, A., et al. (2004). Inquiry in science education: International perspectives. Science Education, 88(3), 397–419.

Allen, P.B. (1983). Conduction of Heat. Physics Teacher, v21 n9 p582-87.

Alonso, M., Finn, E.J. (1995). An Integrated Approach to Thermodynamics in the Introductory Physics Course. Physics Teacher, v33 n5 p296-310.

Anagnos T., McMullin K., Komives C., Mourtos N.J. (2007). Evaluating Student Mastery of Design of Experiment. Proc. 37th ASEE/IEEE Frontiers in Education Conference, Oct. 2007, Milwaukee, WI.

Antoniou, N., Baladakis, A., Dimitriadis, P., Papamihalis, K., Papatsimpa, L. (2000). Physics of B' lower high school. Pedagogical Institute - Publ. of school Textbooks, Athens (in Greek).

Arnold, M., Millar, R. (1994). Children's and lay adults' views about thermal equilibrium. International Journal of Science Education, vol 16 (4), 405-419.

Arnold, M., Millar, R. (1996). Exploring the use of analogy in the teaching of heat, temperature and thermal equilibrium, in: Welford, G., Osborne, J., Scott, P. (ed.): Research in Science Education in Europe: current issues and themes, London, Falmer press.

Bacon, M.E., et al. (1995). Heat, Light, and Videotapes: Experiments in Heat Conduction Using Liquid Crystal Film. American Journal of Physics, v63 n4 p359-63.

Barnes, G. (1991). Nature's Heat Exchangers. Physics Teacher, v29 n6 p330-33.

Baser, M., Geban, O. (2007). Effectiveness of Conceptual Change Instruction on Understanding of Heat and Temperature Concepts. Research in Science & Technological Education, v25 n1 p115-133.

Bauman, R.P. (1992). Physics That Textbook Writers Usually Get Wrong: II. Heat and Energy. Physics Teacher, v30 n6 p353-56.

Besson, U., Viennot, L. (2004). Using models at the mesoscopic scale in teaching physics: two experimental interventions in solid friction and fluid statics. International Journal of Science Education, 26, 1083 –1110.

Bisdikian, G., Psillos, D. (2002). Enhancing the Linking of theoretical knowledge to Physical Phenomena by Real – Time Graphing. In D. Psillos and H. Niedderer (Ed.), Teaching and Learning in the Science Laboratory (pp. 193 – 204). Kluwer Academic Publishers, Netherlands.

Carlton K., (2000). Teaching about heat and temperature, Physics Education 35(2), March 2000.

Carey, S., Smith, C. (1993). On understanding the nature of scientific knowledge. Educational Psychologist, 28(3), 235-251.

Cavallo, Ann M.L. (2001). Convection Connections. Science and Students, v38 n8 p20-25.

Chang, J.Y. (1999). Teachers College Students' Conceptions about Evaporation, Condensation and Boiling. Science Education, v83 n5 p511-526.

Clark D., Jorde D. (2004). Helping Students Revise Disruptive Experientially Supported Ideas about Thermodynamics: Computer Visualizations and Tactile Models, JRST, 411–23.

Cotignola, M.I., Bordogna, C., Punte, G., Cappannini, O.M. (2002). Difficulties in Learning Thermodynamic Concepts: Are They Linked to the Historical Development of This Field? Science and Education, v11 n3 p279-91.

Crawford, B.A., Cullin, M.J. (2004). Supporting prospective teachers' conceptions of modeling in science. International Journal of Science Education, 26 (11), 1379 – 1401.

Drago, P. (1993). Teaching with Spreadsheets: An Example from Heat Transfer. Physics Teacher, v31 n5 p316-17.

Driver, P., Guesne, E., Tiberghien, A. (1985). Children's Ideas in Science, Milton Keynes, Open University Press.

Doerr, E.M. (1997). Experiment, simulation and analysis: an integrated instructional approach to the concept of force, Int. J. Sci. Educ., Vol. 19, No. 3, 265-282.

Du, W.Y., Furman B.F., Mourtos N.J. (2005). On the ability to design engineering experiments, 8th UICEE Annual Conference on Engineering Education, Kingston, Jamaica.

Ebert, J.R., Elliott, N.A., Hurteau, L., Schulz, A. (2004). Modeling Convection. Science Teacher, v71 n7 p48-50.

Economides, M.J., Maloney, J.O. (1978). Two Experiments for Estimating Free Convection and Radiation Heat Transfer Coefficients. Chemical Engineering Education, 12, 3, 122-6.

Edge, R.D., (Ed.) (1993). Thermal Conductivity and Liquid Crystal Thermometers. Physics Teacher, v31 n7 p412-13.

Engel, E., Clough, E., Driver, R. (1985). Secondary student's conceptions of the conduction of heat: bringing together scientific and personal views. Physics Education 20: 176- 182.

Erickson, G.L. (1979). Students' Conceptions of Heat and Temperature. Science Education, v63 n2 p221-30.

Erickson, G.L. (1980). Students' viewpoints of heat: A second look. Science Education, v64, p323- 336.

Fensham, P.J. (2001). Science Content as Problematic - Issues for Research. In H. Behrendt, H. Dahncke, R. Duit, W. Gräber, M. Komorek, A. Kross and P. Reiska (eds.), Research in science education – past, present, and future (Dordrecht, The Netherlands: Kluwer Academic Publishers), 27-42.

Flick, L.B., & Lederman, N.G. (2006). Introduction. In Flick, L.B., & Lederman, N.G. (eds) Scientific Inquiry and Nature of Science. Springer, Dordrecht, pp. ix-xvii.

Frederik, I., Van Der Valk, T., Leite, L., Thoren, I. (1999). Pre-Service Physics Teachers and Conceptual Difficulties on Temperature and Heat. European Journal of Teacher Education, v22 n1 p61-74.

Garratt J., Tomlinson J. (2001). Experimental design-can it be learned? University Chemistry Education, V5 (2).

Gilbert, J.K., Boulter, C.J. (1998). Learning science through models and modelling. In B. J. Fraser & K. G. Tobin (Eds.). International Handbook of Science Education (pp. 53-66). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Gobert, D.J., Buckley, C.B. (2000). Introduction to model-based teaching and learning in science education. International Journal of Science Education, 22, 891 - 894.

Gonzalez-Espada, W.J., Bryan, L.A., Kang, N.H. (2001). The Intriguing Physics Inside an Igloo. Physics Education, v36 n4 p290-92.

Grosslight, L., Unger, C., Jay, E., Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. Journal of Research in Science Teaching, 28(9), 799-822.

Hacking, I. (1992). The self vindication of the laboratory sciences. In: A. Pickering (ed.) Science as Practice and Culture (Chicago, IL: University of Chicago Press).

Harisson, A. Grayson, D., Treagust, D. (1999). Investigating a grade 11 students evolving conceptions of heat and temperature. Journal of Research in Science Teaching, 36 (1), 55- 87.

Harrison, A. G. (2001). Models and PCK: Their Relevance for Practicing and Preservice Teachers. Paper presented at the Annual Meeting of the National Association of Research in Science Teaching, St. Louis, MO.

Hatzikraniotis, E., Lefkos, I., Bisdikian, G., Psillos, D., Refanidis, I., Vlahanas, J. (2001). An open learning environment for thermal phenomena, Proceedings of the 5th International Conference on Computer Based Learning in Science CBLIS , Brno, Czech Republic.

Hausfather, S.J. (1992). It's Time for a Conceptual Change. Science and Students, v30 n3 p22-23.

Heindel, N.D., Warner, N.C. (1969). Early Theories on the Nature of Heat and Light. Sci Educ, 53, 2, 127-130.

Henze, I., Van Driel, J., Verloop, N. (2007). The change of science teachers' personal knowledge about teaching models and modelling in the context of science education reform. International Journal of Science Education, 29(15), 1819–1846.

Hewson, M.G., Hamlyn, D. (1983). The Influence of Intellectual Environment on Conceptions of Heat. Paper presented at the Annual Meeting of the American Educational Research Association (Montreal, Quebec, Canada, April 11-15, 1983).

Hewson, M.G., Hamlin, D. (1984). The influence of intellectual environment on conceptions of heat, European Journal of Science Education 6(3): 245-62.

Johnstone, A.H., Al-Shuaili, A. (2001). Learning in the laboratory; some thoughts from the literature. University Chemistry Education, V.5, 42-51.

Jones, M.G, Carter, G., Rua, M.J. (2000). Exploring the Development of Conceptual Ecologies: Communities of Concepts Related to Convection and Heat. Journal of Research in Science Teaching, v37 p139-59.

Jones, M.G., Rua, M.J., Carter, G. (1998). Science Teachers' Conceptual Growth within Vygotsky's Zone of Proximal Development. Journal of Research in Science Teaching, v35 n9 p967-85.

Justi, S. R., Van Driel, J.H. (2005). The development of science teachers' knowledge on models and modelling: promoting, characterizing and understanding the process. International Journal of Science Education, 27, 549 - 573.

Justi, R.S., Gilbert, J.K. (2002). Science teachers' knowledge about and attitudes towards the use of models and modelling in learning science. International Journal of Science Education, 24(12), 1273-1292.

Karapanagiotis, B., Papastamatiou, N., Fertis, A., Haletsos, H. (1998). Physics of B' lower high school. Pedagogical Institute - Publ. of school Textbooks, Athens (in Greek).

Kattman U., Duit R., Gropengieber R.H. and Komorek M. (1995). A model of Educational Reconstruction. Paper presented at The NARST annual meeting. San Francisco.

Kesidou, S., Duit, R., Glynn, S. (1995). Conceptual Development in Physics: Students' Understanding of Heat, in: Glynn, S. & Duit, R. (eds.): Learning Science in the Schools: Research Performing Practice, LEA Pub, NJ.

Kesidou, S., Duit, R. (1993). Students' conceptions of the second law of thermodynamics – An interpretive study, Journal of Research in Science Teaching, vol. 30 (1), 85-106.

Klahr D., Triona L.M., Williams C. (2007). Hands on What? The Relative Effectiveness of Physics Versus Virtual Materials in an Engineering Design Project by Middle School Students., Journal of Research in Science teaching . 44 (1)183-203.

Knight, C.W., Wohlhagen, L. (1975). Solar Heated Homes: They're Here. Science and Children, 12, 8, 13-14.

Laburu, C.E., Niaz, M. (2002). A Lakatosian Framework To Analyze Situations of Cognitive Conflict and Controversy in Students' Understanding of Heat Energy and Temperature. Journal of Science Education and Technology, v11 n3 p211-19.

Lautrey, J., Mazens, K. (2004). Is Students's Naive Knowledge Consistent? A Comparison of the Concepts of Sound and Heat. Learning and Instruction, v14 n4 p399-423.

Lederman, N.G. (2007). Nature of science: Past, present, and future. In S.K. Abell & N.G. Lederman (Eds.), Handbook of research on science education (pp. 831–879). Mahwah, NJ: Lawrence Erlbaum Associates.

Lefkos, I., Psillos, D., Hatzikraniotis, E., (2005). Integrating ICT tools in a Laboratory Teaching Sequence of Thermal Phenomena. Announced at the 7th International conference CBLIS 2005, Zilina, Slovakia.

Leite, L. (1999). Heat and Temperature: An Analysis of How These Concepts Are Dealt with in Textbooks. European Journal of Teacher Education, v22 n1 p75-88

Lewis, Eileen L., Linn, Marcia C. (1994). Heat Energy and Temperature Concepts of Adolescents, Adults, and Experts: Implications for Curricular Improvements. Journal of Research in Science Teaching, v31 n6 p657-77.

Lewis, E.L. & Linn, M.C. (1994). Heat energy and temperature concepts of adolescents, adults, and experts: Implications for curricular improvements. Journal of Research in Science Teaching, 31, 657–677.

Lewis, E.L. (1996). Conceptual change among middle school students studying elementary thermodynamics. Journal of Science Education and Technology, 5, 3–31.

Liew, C.W., Treagust, D.F. (1995). A Predict-Observe-Explain Teaching Sequence for Learning about Students' Understanding of Heat and Expansion Liquids. Australian Science Teachers Journal, v41 n1 p68-71.

Linn, M., Songer, N. (1991). Teaching Thermodynamics to Middle School Students: What Are Appropriate Cognitive Demands? Journal of Research in Science Teaching, 28, 885 - 918.

Linn M.C., Muilenburg L. (1996). Creating Lifelong Science Learners: What Models Form a Firm Foundation? Educational Researcher Vol.25., No.5., pp18-24.

Linn M.C. (1995). Designing Computer Learning Environments for Engineering and Computer Science: The Scaffolded Knowledge Intergration Framework. Journal of Science Education and Technology, Vol.4, No.2.

Linn, M.C. & Hsi, S. (2000). Computers, teachers, peers: Science learning partners. Mahwah, NJ: Erlbaum.

Mak, S.Y., Young, K. (1987). Misconceptions in the Teaching of Heat. School Science Review, v68 n244 p464-70.

McClelland, A.K., Krockover, G.H. (1996). Students' Understandings of Science: Goldilocks and the Three Bears Revisited. Journal of Elementary Science Education, v8 n2 p32-65.

McIldowie, E. (1998). Introducing Temperature Scales. Physics Education, v33 n6 p368-72.

Meheuet, M., Psillos D. (2004). Teaching – learning sequences: aims and tools for science education research. International Journal of Science Education, Special Issue, 26(5), 515-535.

Millar, R., Osborne, J.F. (Eds). (1998). Beyond 2000: Science Education for the Future. London: King's College London.

Minstrell, J., van Zee, E. (Eds.) (2000). Inquiring into inquiry learning and teaching in science. Washington DC, American Association for the Advancement of Science.

Newell, A., Ross, K. (1996). Students Conception of Thermal Conduction - Or the Story of a Woollen Hat. School Science Review v78 n282 p33-38.

Papaevripidou, M., Hadjiagapiou, M., Constantinou, P.C. (2005). Combined development of middle school students's conceptual understanding in momentum conservation, procedural skills and epistemological awareness in a constructionist learning environment. Int. J. Cont. Engineering and Lifelong learning, 15, 95-107.

Papageorgiou G , Johnson P., Fotiades F. (2008) Explaining melting and evaporation below boiling point. Can software help with particle idea? Research in Science & Technological Education, 26, 2, 165-183.

Petridou, E., Psillos, D., Lefkos, I., Fourlari, S., Hatzikraniotis, E. (2005). Investigating the use of simulated laboratory for teaching aspects of calorimetry to secondary education students, CBLIS 2005, Slovakia.

Psillos, D., Hatzikraniotis, E., Lefkos, I. (2002). Active learning with the use of simulated laboratory. Proceedings of the 2nd International Conference for Science Education, Cyprus (in Greek).

Psillos, D., Niedderer, H. (Eds). (2002). Teaching and Learning in the science laboratory. Dordrecht, Boston, London: Kluwer Academic Publishers.

Pynadath, V.D. (1978). Insulation and Rate of Heat Transfer. Physics Teacher, v16 n6 p379-80.

Ramondetta, J. (1994). Technology. The Hot Cup Caper. Probing for Scientific Knowledge. Learning, v22 n7 p65.

Reif, F. (1999). Thermal Physics in the Introductory Physics Course: Why and How To Teach It from a Unified Atomic Perspective. American Journal of Physics, v67 n12 p1051-62.

Rogan, J.M. (1988). Development of a Conceptual Framework of Heat. Science Education, v72 n1 p103-13.

Rosenquist, M., Popp, B., McDermott, L. (1982). Helping Students Overcome Conceptual Difficulties with Heat and Temperature. Paper presented at the meeting of the American Association of Physics Teachers, Ashland.

Ruck, Carolyn et al. (1991). Using Discrepant Events to Inspire Writing. Science Activities, v28 n2 p27-30.

Rushton, E., Ryan, E., Swift, C. (2001). What is the Best Insulator: Air, Styrofoam, Foil, or Cotton? Grades 3-5. www.prek-12engineering.org/activities/

Russell D.W., Lucas K.B., McRobbie C.J. (2004). Role of the Microcomputer-Based Laboratory Display in Supporting the Construction of New Understanding in Thermal Physics. Journal of Research in Science Teaching.,Vol.41. No.2, pp.165-185.

Saari, H., Viiri, J. (2003). A research-based teaching sequence for teaching the concept of modelling to seventh-grade students. International Journal of Science Education, 25, 1333 - 1352.

Schwarz, V.C., White. Y.B. (2005). Metamodeling Knowledge: Developing Students' Understanding of Scientific Modeling. Cognition and Instruction, 23(2), 165-205.

Schwarz, C.V., Reiser, B.J., Davis, E.A., Kenyon, L., Acher, A., Fortus, D., Schwartz, Y., Hug, B., Krajcik, J. (2009). Developing a Learning Progression for Scientific Modeling: Making Scientific Modeling Accessible and Meaningful for Learners. Journal of Research in Science Teaching, 46(6), 632–654.

Schwarz, C.V. (2002). Is there a connection? The role of meta-modeling knowledge in learning with models. In P. Bell, R. Stevens, & T. Satwicz (Eds.), Keeping learning complex: The Proceedings of the Fifth International Conference of the Learning Sciences (ICLS). Mahwah, NJ: Erlbaum.

Schwarz, V. C. (2002). Using Model-Centered Science Instruction To Foster Students' Epistemologies in Learning with Models. Annual Meeting of the American Educational Research Association, New Orleans.

Sciaretta, M. R., Stilli R., Vicentini M. (1990). On the thermal properties of materials: common –sense knowledge of Italian students and teachers. Int. J. Sci. Educ., No. 4, 369-379.

Seel, M. N. (2003). Model-Centered Learning and Instruction. Technology, Instruction, Cognition and Learning, 1 (1), 59-85.

Shayer, M., Wylam, H. (1981). The Development of the Concepts of Heat and Temperature in 10-13 Year-Olds. Journal of Research in Science Teaching, v18 n5 p419-34.

She, H.C. (2003). DSLM Instructional Approach to Conceptual Change Involving Thermal Expansion. Research in Science and Technological Education, v21 n1 p43-54.

She, H.C. (2004). Fostering Radical Conceptual Change through Dual-Situated Learning Model. Journal of Research in Science Teaching, v41 n2 p142-164.

Smyrnaiou Z., Politis P., Komis V., Dimitrakopoulou A. (2004). The role of real and virtual experiments in science learning. Paper presented at CBLIS Conference Cypros.

Stinner, A.O. (1978). A Solar House for Northern Latitudes. Physics Teacher, 16, 1, 25-30.

Switzer, T.G. (1984). When You're Hot... Science Teacher, v51 n6 p58-61.

Taber K. S. (2000). Finding the optimum level of simplification: the case of heat and temperature, Physics Education 35(5), September 2000.

Taylor, J.R. (1989). Firewalking: A Lesson in Physics. Physics Teacher, v27 n3 p166-68.

Thomaz, M., Malaquias, I., Valente, M., Antunes, M.J. (1997). An attempt to overcome alternative conceptions related to heat and temperature. Physics Education, v.30 (1), 19-26.

Tiberghien, A. (1983). Critical review on the research aimed at elucidating the sense that the notions of temperature and heat have for students aged 10 to 16 years. Research on Physics Education, Proceedings of the first international workshop, Editions Du Centre National de la Recherche Scientifique, Paris, pp. 75-90.

Tiberghien A. (1985). Heat and Temperature: Part B: The development of ideas with teaching, in R. Driver, E. Guesne & A. Tiberghien: Students' Ideas in Science, Milton Keynes, Open University Press.

Treagust, D.F., Chittleborough, G., Mamiala, L.T. (2002). Students' understanding of the role of scientific models in learning science. IJSE, 24, 357 – 368.

Van Driel, J.H., Verloop, N. (1999). Teachers' knowledge of models and modelling in science. International Journal of Science Education, 21(11), 1141-1153.

Van Driel, J.H., De Jong, O. (2003). Investigating the development of teacher knowledge of models and modeling in science. Paper for the 4th ESERA Conference, Noordwijkerhout.

Vaquero, J.M., Santos, A. (2001). Heat and Kinetic Theory in 19th-Century Physics Textbooks: The Case of Spain. Science and Education, v10 n3 p307-19.

Wang, S.F., Grossman, S.J. (1987). Plastic Materials for Insulating Applications. Journal of Chemical Education, v64 n1 p39-41.

Ward, A. (1973). Investigating Heat. Science Activities, 9, 1, 22-23.

Warren, J. W. (1972). The Teaching of the Concept of Heat. Physics Education, 7, 1, 41-44.

Watson, R., et al. (1995). The Effect of Practical Work on Students' Understanding of Combustion. Journal of Research in Science Teaching, v32 n5 p487-502.

White, B.Y., Frederiksen J.R. (1998). Inquiry, modeling, and Metacognition: Making Science Accessible to All Students. Cognition and Instruction 16,1, 3-118.

Widick, P.R. (1975). Light Energy Into Heat Energy. Science Activities, 12, 1, 37-38.

Windschitl, M., Thompson, J., Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. Science Education, 92(5), 941–967.

Windschitl, M., Andre, T. (1998). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs, Journal of Research in Science Teaching, 35(2).

Windschitl, M., Thompson, J. (2006). Trancending Simple Forms of School Science Investigation: The Impact of Preservice Instruction on Teachers' Understandings of Model – Based Inquiry. American Educational Research Journal, 43(4), 783-835.

Windschitl, M. (2001). Using Simulations in the Middle School: Does Assertiveness of Dyad Partners Influence Conceptual Change? International Journal of Science Education, vol.23, no. 1, 17-32.

Wiser, M. (1986). The differentiation of heat and temperature: History of science and novice - expert shift. In S. Strauss (ed.), Mental models, Hillsdale, VJ, Lawrence Erlbaum, 267-298.

Wiser & Amin, (2001). "Is heat hot?" Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena. In L. Mason (Ed.) Instructional practices for conceptual change in science domains [Special Issue]. Learning & Instruction, 11, 331-355.

Wolfgang, C., Belloni, M. (2003). Physlet Physics: Interactive Illustrations, Explorations and Problems for Introductory Physics. Prentice Hall.

Zemansky, M.W. (1970). The Use and Misuse of the Word "Heat" in Physics Teaching. Phys Teacher, 8, 6, 295-300.

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