AN INNOVATIVE INQUIRY-ORIENTED MODULE ON THERMAL CONDUCTIVITY: DESIGN, DEVELOPMENT AND APPLICATION

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ABSTRACT

In line with current trends about developing teaching learning sequences in science education we have designed an innovative inquiry oriented module aiming at providing secondary education students with a comprehensive treatment of thermal conductivity in materials. The module, developed in the context of the European Project on Materials Science, consist of units which make an extensive use of ICT-based tools, including virtual laboratories and specially developed parametric simulations of microscopic models on heat conduction as well as hands-on experiments. The structure of the module is presented here as well results from classroom applications, which include pre-post tests, teachers' notes and video taped lessons. Preliminary pre- and post-test results showed moderate evolvement in students' understanding of concepts and process of heat conduction in different materials.

KEYWORDS

ICT-based learning, inquiry-oriented learning, thermal properties of material, thermal conductivity

INTRODUCTION

Thermal phenomena, heating, cooling, and related scientific concepts, models and theories, is a topic area that educators and researchers consider both 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 and Glynn, 1995) has shown that students and to a certain extend teachers, hold intuitive views which are related to their everyday experiences. Students usually face difficulties in differentiating the concepts of heat and temperature, do not take into account all the parts of an interacting thermal system and often neglect the environment, especially surrounding air. Students do not necessarily believe that objects that are in thermal contact will interact and will tend towards thermal equilibrium, thus, acquiring 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 as "heat movement, hotness movement, heat transfer" but also use "coldness movement". However, they often fail to focus on how heat transfer occurs, or, tend to provide alternative explanations for transfer mechanisms in solids liquids and gases (Engel E., Clough E., and Driver 1985, Sciaretta M.R., Stilli R. and Vicentini M., 1990). Construction of unified views on what happens in thermal 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 field of Heat and Temperature, focus on helping students construct their understanding of the concepts of 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 and Millar, 1997). Clark and Jorde (2004) analysed 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 and 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 thermal conduction. Thermal conduction refers normally to heat transfer in solids without mass movement. A comprehensive treatment of thermal conductivity requires some understanding of the basic concepts in the field of heat, as well as, of factors and mechanisms involved in conduction. It is usually beyond the focus of compulsory education curricula. However, from the point of view of introductory materials, Science conductivity is an essential property of natural materials and advanced technology artefacts. The field of application of this process is widespread and involves ceramics and polymers, metals and alloys composites and relevant natural or synthetic materials, artefacts and applications such as glasses, cooking devices, jackets, ceramic ovens, insulating Styrofoam, to name only a few materials whose conductivity affects everyday experiences. From a social point of view, students and adults experience frequently in their everyday lives phenomena related to conduction in situations like cooking, take decisions about using artefacts 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 workplace.

We consider that it is educationally significant and socially relevant to provide opportunities for students to become familiar with material science and specifically to engage in inquiry about thermal conduction of materials, to extend their knowledge of basic concepts in the field of Heat and construct their understandings in the context of contemporary technological applications. The present work was undertaken against this background and is carried out in the context of the recently started European Project which aims at developing innovative approaches towards introducing aspects of Material Science in compulsory education and enhancing secondary students' understanding of scientific inquiry. Several groups of researchers and teachers from European countries participate in this project. In this paper we present essential design features as well as developmental process and initial results concerning a module, (or teaching learning sequence, see further on) which aims at enhancing students' understanding of conductivity.

OVERVIEW OF THE CONCEPTUAL BUILDING BLOCKS

In this section the basic conceptual blocks of the module are presented. The research and development approach, which has been followed, is outlined in the section on the design of the model.

i) Approaching science and science teaching

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 coping with their 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 (Hacking, I. 1992). This sort of laboratory-centred interventionist practice supports theoretical productions and distinguishes scientific literacy from other types of literacy (e.g. philosophical or literary). 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. Recent proposals focus on teaching of science through inquiry which aims at enabling students to obtain experiences that are parallel to authentic scientists' experiences and is thought to make their learning more meaningful and to improve their scientific understanding (Minstrell and Van Zee, 2000, Windschitl M., and Thompson J. 2006). Science educators consider inquiry 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 and manipulate data, explore appropriate conceptual models, think about relationships between evidence and explanations and communicate scientific arguments.

ii) Analysing scientific content

Briefly speaking, heat transfer by conduction involves transfer of energy within a material without mass transfer. The rate of heat transfer depends upon the temperature gradient and the thermal conductivity of the material (Kallister, 2000). Thermal conductivity (κ) is a reasonably straightforward concept when one discusses heat loss through the walls of his/her house. 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. For heat transfer between two plane surfaces, such as heat loss through the wall of a house, the rate of conduction heat transfer is**:**

$$\dot{Q} = \kappa \cdot \frac{A}{d} \cdot (T_{HOT} - T_{COLD})$$

where ***Q*** is the rate of heat transfer, ***κ*** is the thermal conductivity of the barrier, ***A*** is the area of the barrier, $\boldsymbol{T_{COLD}}$, $\boldsymbol{T_{HOT}}$ are the temperatures at the two sides of the barrier, and ***d*** is the thickness of barrier. The thermal conductivity of a system is determined by how atoms comprising the system interact. There are no simple, correct expressions for thermal conductivity. In metals, thermal conductivity mainly depends on the electrical conductivity of the material. In non-metallic material the phonons in the system are known to scatter. Thus, in a general case, thermal conductivity has two contributions, the electronic part (κ_e) and the lattice one (κ_L), namely, $\kappa=\kappa_e+\kappa_L$

iii) Reconstructing scientific models

Scientific models of conductivity must be adapted to students in order to be learnable. We consider that understanding of conductivity implies modelling and educational transformation of scientific knowledge at different levels. Thus students will be engaged in model exploration and construction of links between models as well as models and properties of materials (Gilbert J. K., and Boulter C. J., 1998, Windschitl M., and Thompson J. 2006).

iii.a) Macroscopic models

A "heat flow" model as depicted in figures 1a,b has been used to illustrate the thermal interactions either in a two-body case, or in a single body. Research has shown that the "heat flow" model appeals to students (Linn and Muilenburg, 1996), yet it does not focus on the thermal conductivity of materials. For this reason we opted to extend the "heat flow" model, as to incorporate material properties and specifically thermal conductivity (figure 1c, d).

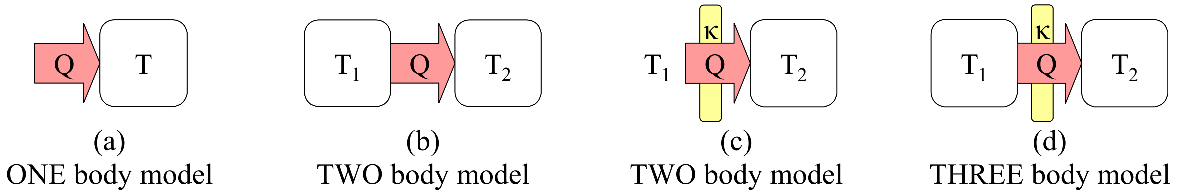

Figure 1. Heat flow models

In reference to figure 1, the first of the models (fig.1a) represents a single-body heat flow model; heat flows to the body, causing a rise in its temperature. A typical example is the calorimetry experiment. In this example, one does not care *why* heat flows; it is taken per se. This question is addressed in the second of the models (fig.1b), where, heat is transferred from a body at higher temperature (T_1) to another at lower temperature (T_2). A typical example for this 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 1b; heat flows to the body through a barrier of thermal conductivity "κ". It is a more realistic example, for heating water inside a beaker, for example; the rate of heat transfer depends on the temperature difference (T_1-T_2), as well as on the beaker's surface, thickness and thermal conductivity. Similarly, the model shown in fig. 1d, is a 3-body model, which extends model 1b. Extended models try to address the question *"how fast does heat flow"*.

iii.b) Microscopic models

Simplified microscopic models have been developed for the mechanism of heat transfer in different types of materials. A set of rigid balls arranged in a matrix form simulates the lattice. 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. Free electrons are depicted as small red balls for visualization purposes. The motion of free electrons in a metal solid is limited within the neighbourhood of 4 adjacent atoms. In the simulation of a composite material, we assume that it consists of a crystalline solid with voids that contain air; air molecules are depicted by the small white balls, that travel and bounce within the void.

iv) Employing an enriched learning environment

Traditionally, school experiments on thermal phenomena are thought of as easily conducted in a classroom, without any 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, inside a school laboratory, albeit the hands-on experience, students often end up filling up the worksheets mechanically, without really giving a meaning to the actual process, or 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 specially 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 E.M., 1997).

The module consists of hands-on experiments, simulated experiments and microscopic model simulations. The macroscopic observations are carried out by real (hands-on) experiments, as well as, simulated (computer) experiments, while parametric simulations visualize the microscopic models. 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 balls start to fall one by one.

Virtual experiments have been effective in science teaching (Klahr D., Triona L.M. and Williams C. 2007), can hinder the slow nature of thermal interactions and allow experimenting in "extreme" conditions and easy manipulation of variables. Inquiry refers to posing questions, making observations, designing investigations, collecting information, analyzing and interpreting data and constructing and communicating explanations. Taking into consideration both of the above the approach of combining real and virtual experiments with microscopic models can form a basis suitable for inquiry-oriented learning that can be considered innovative in the sense that it may provide an experiential learning deriving from the combination of all three of them and incorporating all skills included in inquiry.

We opted to use ThermoLab which is an open learning environment suitable for studying thermal phenomena (Lefkos I., Psillos D., Hatzikraniotis E., 2005). A typical screenshot for the Thermolab is presented in Figure 2a. 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 be investigated, 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.

The Flash simulations for simulated labs (shown in Figure 2b) 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.

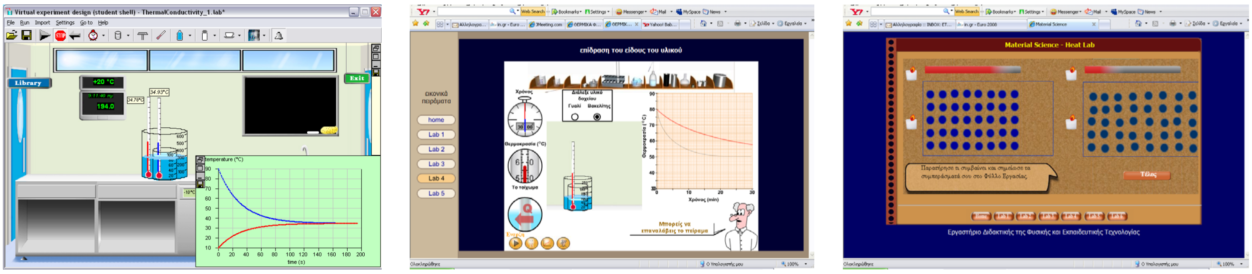

Figure 2. (a) ThermoLab screenshot, (b) simulated lab and (c) microscopic model

In both types virtual labs, real time graphs provide conceptual bridges that help students scaffold links between observations of thermal conduction and relevant models (Bisdikian, G., and Psillos, D., 2002)

Literature suggests that visualizations are effective in supporting students' identification of "how things work". Flash simulations were developed for microscopic models one example of which is shown in Figure 2c for ceramics. It consists of a set of rigid balls arranged in a matrix form to simulate the lattice. The balls are vibrating with smaller or larger amplitude, according to temperature. Students are asked to observe the vibrational motion of the balls as the temperature rises. Visualization becomes more complicated for composite materials. Composite materials are engineered materials made from two or more constituents with significantly different physical or chemical properties, which remain separate and distinct on a macroscopic level within the finished structure. We have tried to demonstrate thermal conductivity for the case of air inclusions in a solid matrix. The solid structure in this case is depicted as a network of vibrating spheres and voids in the network structure, where air molecules are moving; air molecules are depicted by small white balls that travel and bounce within the void, transferring the heat.

Virtual experiments have been effective in science teaching (Klahr D., Triona L.M. and Williams C. 2007), can hinder the slow nature of thermal interactions and allow experimenting in "extreme" conditions and easy manipulation of variables. Taking into consideration the above, the approach of combining real and virtual experiments, which afford real time graphing, with educationally transformed microscopic models, can form a basis suitable for inquiry-oriented learning that can be considered as innovative. It provides for an enriched environment, which affords students to interact with real, and then more idealized simulated experiments and combine macroscopic observations with exploration of microscopic processes.

MODULE DEVELOPMENT AND RESEARCH

In line with the aim of the Materials Science Project we follow recent practice, which involves the development of topic-oriented teaching learning sequences (TLS) 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 (for a review on research, see Méheut & Psillos, 2004). A teaching –learning sequence (TLS) is both a research process and a product, similar to a traditional curriculum unit package, which includes well-researched teaching/learning activities. Often a TLS develops gradually out of applications according to an iterative 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. 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 in line with the project.

The “educational reconstruction” model has been chosen as a theoretical framework for designing and validating the 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’ conceptions and choices regarding instruction (Duit R., Roth, W-M, Komorek, M. & Wilbers,J. 1999). Scientific content as well as instruction has to be (re)constructed by developers of research based modules who take into account students’ conceptions as well as empirical results from classroom applications.

A brief analysis of the scientific content and its adaptation for lower secondary education, approaching science as inquiry as well as the relevant experiments and simulations are presented in the section on the conceptual blocks. In the following we outline the reconstructed content structure and suggested instruction as well as empirical results, which inform the revision of the module. Planned research aims at providing evidence for the effectiveness of the module in enhancing students’ understanding of thermal equilibrium of bodies and their environment, thermal conductivity in different materials, the process of thermal conduction, the feasibility of applying the module in a traditional setting, and of enhancing students’ interest and motivation towards science. In the present paper we focus on selected preliminary results, which are drawn out of an initial application. The aim was to try out the materials and investigate whether it is feasible to apply such a module as an extension to the theme ‘heat transfer’ included in the topic area ‘Heat’ of the curriculum and investigate aspects of students’ understanding of conduction as noted previously.

Teaching of physics in Greece is normally based on traditional transfer of knowledge practice. The curriculum is centrally designed and implemented in a rigid way. Physics, including chapters on Heat and Temperature, is compulsory taught at 2nd form. Teaching is usually approached in a traditional trasfer of knolwedge manner. However, a special legal arrangement allows for flexible treatment of particular disciplinary and interdisciplinary themes as extending school topics to be taught during a posrtion of school time. Within this context the module has been developed by as an extension of the section “Heat conduction” of the chapter “Heat and Temperature” of the Greek curriculum.

A local working group (LWG) was established for developing and investigating the module. The LWG consists of researchers in science education and solid-state physics, experienced teacher–researchers with works in science education. Experienced physics teachers cooperated with the group. The researchers and teacher–researchers carried out the main developmental work as well as the design of research activities. In addition teacher-researchers tried out certain units in classrooms by cooperating with the teachers. The experienced physics teachers familiarized, discussed and commented on the materials and the feasibility of applying the suggested activities in classrooms used to traditional teaching. Before teaching they also familiarized with all ICT and hands on materials by trying them out and discussing them with the researchers. The work of the LWG did not follow a linear objectives – activities - application design model. Instead, there were cycles of proposing, discussing, and revising by all participants before applying the module in classrooms.

The present version of the module is structured in 6 modular units as following.

- *Unit 0*: Introductory - Familiarization Unit
- *Unit 1*: Thermal Equilibrium and Thermal Conductivity
- *Unit 2*: Thermal Conductivity in crystalline and amorphous materials (Ceramics and Polymers)
- *Unit 3*: Thermal Conductivity in Metals and Alloys
- *Unit 4*: Thermal Conductivity in Composite Materials
- *Unit 5*: Student Report

The first of the Units is introductory. It is used to familiarize students both with the content and the methodological approach. Heat transfer/thermal equilibrium concepts are accounted for, which are basic for the module. Additionally, students are introduced to investigative work through experiments, e.g. set up of real and simulated experiments, graph interpretation, exploration of microscopic models. In Unit 1, the concept of "Thermal conductivity" is introduced and is further elaborated in Unit 2 (Thermal conductivity in crystalline and amorphous materials), Unit 3 (Thermal conductivity in Metals) and Unit 4 (Thermal conductivity in Composite Materials). In Unit 5 students are planned to report on small projects. A teacher can follow the suggested overall sequence but can decide whether he will modify this structure.

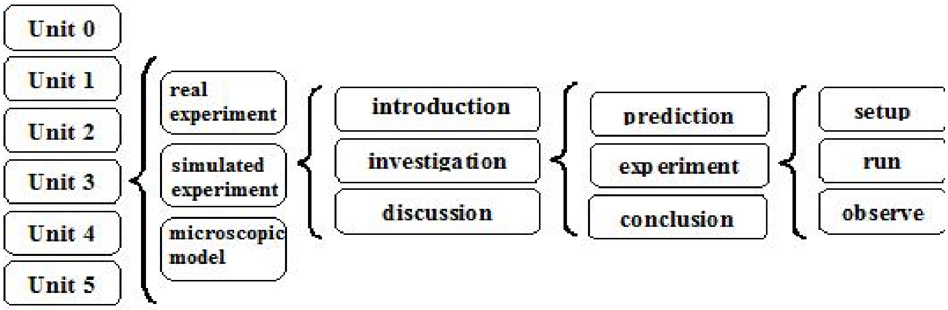

Figure 3. Example of the unfolding structure of the sequence (The case of Unit 3 is exemplary). Students' worksheets (WS) are designed on the basis of the (POE) pattern, as described above.

In Figure 3, we present the unfolded structure of one unit. Units include introductory familiarization phase, where contextualized everyday-life problems are presented to students. These units are designed so that:

- Students work in groups of 2-4, solve problems, explore models and are engaged in classroom discussion on the problems at study.
- Students are engaged in laboratory type sessions, in which they interact with hands-on and simulated experiments and make macroscopic observations following structured worksheets based on a guided inquiry and the Predict-Observe-Explain (POE) pattern.
- Microscopic models are presented by the teachers and then explored by the students for interpreting conduction phenomena.
- Teachers provide guidance to the students, coordinated the running of experimental activities, introduced models and led discussions.

Every worksheet includes information about the objectives, the materials and some theoretical information in certain cases. Collaborative activities are proposed, in order for the students to share and interpret data, discuss specific questions of the worksheets and reach conclusions. In general, each WS refers to several student activities. An indicative structure is as following, which may be repeated throughout one unit:

Phase 1
Students are introduced to the phenomena under study, usually by solving a qualitative problem. The problem to be solved usually comes from everyday experiences, in order to be meaningful for the students. For example, from the worksheet that interprets the surface as a factor which affects heat transfer, the problem set is this: *"The milk that a mother had prepared for her baby was too hot. In order to make it cool down sooner she poured it into a larger pot, which had walls with same thickness. Do you agree with her action and why?"*

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

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

Phase 4
Students compare their predictions with the experimental results of previous phases take into account conceptual models, draw conclusions and discuss in the classroom.

MODULE IMPLEMENTATION AND DATA COLLECTION

The fist pilot application of the module was carried out during the fall semester of 2007-008. As mentioned above the setting was lower secondary compulsory school in Greece. The module was implemented by three experienced physics teachers, in a sample of 67 students, aged 14, in four different high school classes. It should be noted here that these students were introduced to basic concepts of heat and temperature ahead of the module implementation and were familiarized with hands on experiments, such as measurement of temperature of water in a beakers. They were also familiarized with the use of 'ThermoLab'; for example, they set up experiments, took virtual measurements of temperature of water in a beakers and related data with the real time graphs. They also recorded thermal equilibrium between two same quantities of water and between two different quantities of water with different initial temperature. Familiarization with the "Thermolab" was easy for these students due to its friendly and appealing environment.

Prior to the implementation of the module, students' conceptions were investigated. A questionnaire consisting of 9 questions was used, a sample of which is included in the appendix. Questions were based on events and experiences from every day life. Students were asked to give written documentation of their choices. Students' ideas were investigated, amongst others, on thermal equilibrium and insulation, on ranking materials depending on their thermal conductivity, on processes of heat transfer through materials (conduction)- 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. A post-test questionnaire featuring all pre-test questions and additional new ones (see appendix) concerning knowledge introduced by the module was administered to the students at the end of the module 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 module, a 'one question post-test' was administered halfway between the implementation of the whole module (see also appendix).

Three sources of data were used to monitor the module implementation. a) video recordings of eight classroom lessons in one of the schools in which this was feasible. The videotaped lessons included classroom interactions; teacher introduction, classroom discussions and students group work. b) Personal notes which teachers had made available that included comments on the module, and difficulties faced when implementing the module. c) Oral communications with the teachers. These provided additional information, which supplemented features of 'classroom reality' recorded by the videos. Data coming from all three sources provided valuable information and insights that contributed largely to the revision and adaptation of the module that is currently carried out by the LWG.

RESULTS AND DISCUSSION

Qualitative analysis of the students' written documentation was employed. The analysis procedure used identification of regularities in the first stage followed by a constant comparative technique. Each question was separately analysed and findings were recorded in all stages of the analysis. Selected results are as follows:

- *Thermal equilibrium of bodies and their environment*: While in the pre-test approximately 3% of the students' answers were considered scientifically acceptable, there was a desirable change in their ideas, which was identified in 30% of them. These students seem to have acquired the main idea of thermal equilibrium of bodies and their environment. An example of the newly expressed ideas is the following: *The objects in the house will acquire the temperature that the house has.*

- *Heat conduction through mater*: While in the pretest 3% of the students made reference to the 'building blocks' of mater, in the mid post-test 42% made use of a microscopic explanation. Of these explanations 10% can be characterized scientifically acceptable. Comparison with the results of the post-test analysis revealed that there was a small reduction in the number of the students making reference to the microscopic explanation. There were also 'incomplete' explanations, e.g *Atoms collide and this is how temperature rises*, as well as some misconceptions that appeared for the first time in the explanations of this item such as that the changes of the thermal state of a body results from the changes of the thermal state of the molecules: *The closest to the heat source molecules are heated and in succession they heat the rest of them.*
- *The_microscopic processes of heat conduction in different categories of materials*: The analysis showed that almost half of the answers were fully acceptable. In the rest either there was no answer or the answer indicated that the students could not identify the correct mechanism of heat conduction, e.g. *Heat transfer in composite materials is done exclusively by the moving electrons.*

The above reported results may indicate the following: Regarding 'thermal equilibrium of bodies and their environment', although there was a desirable change in students' ideas, this was identified in 30% of them. A possible explanation could be the following: While in the pre-test questionnaire students' understanding was investigated for bodies and the surrounding atmosphere, the experiments aiming at improving their ideas did not involve the same context. In these experiments instead of air water was used. Thus, may be, when the students answered again the specific item in the post-test questionnaire, did not make the link between water and air as the bodies' environment. Regarding 'heat conduction through mater' it seems that a good number of students recorded the role of the molecules in heat conduction. Possible reasons for the small number of the scientifically acceptable explanations and certain new appearing misconceptions could be that they have not fully understood the underlying process. Findings related to students' understanding of 'the microscopic process of heat conduction in different categories of materials' showed that half of the answers were almost correct. Yet findings for the incorrect answers may indicate that half of the students did not acquire knowledge for the differentiation of the heat conduction process in differently structured materials.

Video taped lessons were observed and discussed by two LWG members in order to acquire a picture of "classroom reality" with emphasis on the completion of the worksheets, students' engagement in required tasks, teachers' guidance and classroom discussion. Observations by the researchers, coupled by all teachers' notes suggested that the students managed to cope with this innovative environment; they were actively engaged in carrying out the worksheets tasks during the real and the simulated experiments and exploration of the microscopic models; they found the module interesting; for example, two of the teachers noted that they were impressed that in the 1rst unit following instructions their students managed to cope with team work required to carry out a complicated experimental work since they split roles, recorded and discussed results in their groups and in classroom. However, data from these sources indicated that in certain cases the required activities were too many and demanding for the available time of implementation. For example, in unit 2 the study of density as one parameter that affects thermal conductivity in ceramics in both heating and cooling experiments appeared too time consuming and conceptually demanding.

It was also noted that in certain units the students were more occupied with performing the experiments than with evaluating results. Classroom discussion, though planned by researchers and teachers was not adequate during the course of activities. The teachers provided guidance to their students when necessary yet in certain cases they were rushing to cope typically with all suggested tasks letting less time for a concluding classroom discussion. For example, in unit 2 it was noted that in all classrooms the students were preoccupied with fulfilling the tasks all along the worksheet had hardly any time for classroom discussion. The same comment applies to the teachers as well who, at times, preferred to prompt students finish all the planned activities as in traditional teaching rather than showing creative adaptation of the inquiry tasks during teaching.

From oral communications with teachers it emerged that after teaching they changed their opinion about certain ICT materials though they initially agreed that all simulations were appropriate for the students. An example is unit 4 in which students are introduced to a simplified microscopic model for the nature of heat conduction in composite materials. However, all teachers agreed that the students did not seem to have understood the simulation, which was described previously, probably because the solid structure, due to space reasons, was depicted only by two columns of particles on each side.

CONCLUDING REMARKS AND IMPLICATIONS

In line with current trends about developing teaching learning sequences in science education we have designed and developed an innovative research based inquiry oriented module aiming at providing compulsory education students with a comprehensive treatment of thermal conductivity in materials. Gradual revision and improvement of the module in cycles of iterative development based on empirical results is carried out.

Results are currently under study. Preliminary findings of the comparative pre-post analysis indicate moderate improvement of students' understanding of the addressed by the module concepts and process of heat conduction in the different materials. The results of the other sources support the applicability of the module yet they also indicate some difficulties in implementing the planned inquiry activities. Taking into consideration that a sound understanding of the above concepts and processes was expected from students, the findings point out to specific revisions that should be made before the module's final implementation. The empirical findings provide a context for the revision of the module. We consider that the shortcomings indicated by the analysis may be due to on the one hand the weakness of the module itself regarding the content and activities involved, and on the other to the way the activities of such an inquiry oriented module were implemented by teachers and carried out by students, who are familiar with traditional teaching.

Revisions will mainly target the following: With regard to the content the composite materials are planned to be treated only at a descriptive level in the main units. In depth study of the underlying process will be optional and the relevant microscopic simulations will be modified. The design of the activities will change in certain cases, most notably for density in ceramics, so that demands will be lessened to those that are most relevant to the aims of the present study. More tasks prompting students to discuss on results in order to link experimentation with critical reflection on evidence will be included. With regard to teachers' preparation, on the one hand a more detailed teachers' guide including explicit notes will be formed and on the other, employing video based observations, a base will be formed for reflective discussions on how to implement the module creatively and move away form traditional teaching.

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APPENDIX (Sample of questionnaires' items)

Pretest

Question: During winter you visit your country house in the mountains. The temperature inside the house is 6^{o}C. There are different items left in the house. Can you predict what will the temperature of the following objects be?

a. A woollen sweater
b. A metal saucepan
c. A wooden table

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

Question: 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:

a. Wood absorbs and stores heat while the metal doesn't
b. Metal and wood have different temperatures
c. The metal conducts heat faster than wood does
d. Wood absorbs the cold
e. The metal absorbs the cold

Choose those answers that you think are correct and justify your choice.

Post-test

Question: Two adjacent stores have facades with the same surface area. One is made of Plexiglas and the other of glass both of which have the same thickness and belong to amorphous ceramic materials. If on a cold winter day the heating system breaks down, what piece of information you need to know in order to decide in which of the two stores the staff will feel cold sooner.

Mid Posttest

Question: 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?