Students Designing their own Experiments on Heat Transfer Phenomena Using Sensors and ICT

An Educational Trial to Consolidate Related Scientific Concepts

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***Abstract*—Following our previous research effort, the present study focuses on a laboratory practice utilizing sensors and ICT, and follows the change in the perceptions students have in relation to the concept of heat transfer. The present paper builds on the experience gained and refines the techniques used. The new sample consists of a larger group of 16-20 year old students, all studying mechanical engineering in a vocational school. A novel and creative research approach was followed. Students were asked to use their experience so as to design, create, calibrate, and use an experimental setup so as to demonstrate heat transfer phenomena. All students used heat sensors and appropriate ICT-systems. Our aim was to improve students' comprehension concerning heat transfer. The 122 students forming the total sample were split into an experimental group of 64, which is the one that was asked to design, create, calibrate, and subsequently use a school-experiment, while a control group of 58 of student-users only used the experimental setups of the experimental group (without any creative design). Both questionnaires and personal interviews were used to collect the research-data. Subsequent data analysis indicates that, when the questions are relevant to the creation of the experimental setup, the experimental group exhibits a higher percentage of correct or partly correct answers in comparison to those of the control group, whereas any differences observed in the rest of the questions lie within the limits of the total measurement errors. The use of ICT-systems in the present educational effort is proving invaluable. Some interesting conclusion are drawn which are discussed herein.**

***Index Terms*—ICT in education, sensors, physics education, physics teaching, school-lab experiments, heat transfer, heat transport, thermal conductivity, hands-on experiments, new learning models and applications, real world experiences**

I. INTRODUCTION

Two science concepts often mutually confused by many students, are temperature and heat. This confusion being more pronounced in Greece due to the two terms sounding similar in Greek (i.e. they both start with *thermo-*). Loose everyday language compounds to the problem, even when referring to simple macroscopic heat-transfer in non-equilibrium conditions, representing some of the most common school-lab experiments relating to heat. Even when students succeed in performing all the experimental steps, their comprehension is still lacking a lot, as we observe them (at best) reverting to simple qualitative arguments [1-8], when asked to describe the experiment and explain the results. The present study is a sequel of a previous research effort [9] building on the experience already gained, and refining the techniques used. Putting in good use the students' initiative, they were now asked to design on their own an experimental setup to demonstrate heat transfer phenomena, and then create, calibrate, and use it to its best effect.

One of the uses of ICT in large physics experiments is to allow accurate real-time data-capture and storage. Real-time processing of experimental data follows, and all resulting information is graphically depicted in easy-to-understand diagrams to control the experiment; high-energy physics is one such example. These days, the abundance of inexpensive processing power allows the use of such techniques in the school laboratory, thereby helping students focus their efforts towards the phenomena as these develop in real time, their interpretation, and (ultimately) their easier comprehension. In our present educational trial heat-sensors were used as primary data taking devices, in order to teach the thermal attributes of materials and heat transfer.

II. PREVIOUS RESEARCH EFFORTS

The ideas of children with regard to heat, temperature, and the various processes for the transmission of heat were the subject research in Science Education in many countries for the last thirty years. A particularly good summary-picture can be found on the internet at Students construct their own conceptions regarding heat and temperature through everyday life experience and their own intuition and, in many cases, their conceptions are not compatible with those of scientists. We will briefly present herein some of these alternative student's ideas with regard to the heat, temperature, and the transmission of heat, as these were previously presented in the work of other researchers.

Young children talked of heat in static terms [10] as residing in objects. Slightly older children related the hotness to themselves. The children described heat in spatial and dynamic terms [10]. The children consider heat as "substance" which either can flow either in or out of the bodies, somehow like the air [11, 12] or can flow from one point to another [13]. Erickson [12, 14] found that children construed heat to be a substance that could be added or removed from an object. Students do consider [15] in enough cases "cold" as material entity different from "hot", while seven distinguishable models for the concept of heat were recognized in students.

The differentiation between the concepts of heat and temperature has been the subject of considerable research. A number of studies [1-5, 17-22] have shown that children as well as adolescents do not distinguish between them at all. Students believe [12] that "… the temperature of a body is related to its size or the amount of "stuff'' present. This "amount criterion" for the judgment of temperature may well be one of the root causes of the confusion between heat and temperature that seems to exist in the minds of many children and some adults.. ". Thus the students tend to consider [12] that "… temperature is a measure of the mixture of heat and cold inside an object.." and that ".. all objects contain a mixture of heat and cold…". Many students consider [12, 14, 21, 23-27] temperature in terms of a quantitative entity. As an example, students tend to summate temperatures of water [23, 28] when they were asked, questions like ''what would happen to the temperature of water, if water with different temperatures were combined?''. Also, children have a lot of difficulty treating temperature as an intensive variable [29].

Students also consider temperature as a property that characterized the different materials. For example, students were unable to perceive that different materials could have the same temperature under equal conditions [23], and they presumed that materials could be categorized as cold, medium, or hot. Students of 11th grade had conceptions of temperature being a measuring instrument for heat. Even some university freshmen, do not differentiate between heat and temperature [6] and, after having responded correctly in a context that approximates the kinetic view of heat, they fall back on the caloric (as opposed to kinetic) theory of heat, i.e. "as some kind of liquid flowing".

Students' conception of heat transfer is separated in "hot" and "cold" transfer, as they appear to think that heat transfers from a hot object while cold "air" transfers from a cold object, and thus conceptualize heat as a transferring material [12, 23, 24, 30, 31].

Erickson [12] studied the ideas of students with regard to the conduction of heat in a metal rod that is heated at one of its ends. He realised that the students believe that "..the whole rod gets hot because: The heat builds up in one part until it can't hold any more and then it moves along the rod.." According to him, this concept illustrates the material aspect of heat.

Watts & Gilbert studied the ideas of students with regard to the conduction of heat in a metal rod that is heated at the one of its ends, and is cooled in the other [16]. They realised that the students believe that there exist "hot molecules" that move along the rod, from the hot to the cool end where they get cold and where their motion stops.

Students tend to believe [12, 24]1 that the transfer method differs according to material properties and consider that heat transfer depends on the particular material. Researchers believe [32] that this may be the reason why students did not appear to easily comprehend the concept of heat equilibrium, and hence that the temperature of a material differs according to atmospheric temperature.

III. RATIONALE OF THE PRESENT STUDY AND EDUCATIONAL HYPOTHESIS

School-lab exercises represent a fundamental element in the teaching of Science. Such lab exercises are meant to be executed in strict adherence to the corresponding theoretical teaching models, and are shown to help students comprehend the corresponding subject. A well designed laboratorial activity would, therefore, have to ensure that the students: a) become familiar with experimental equipment, b) comprehend the operation of experimental setup, c) follow the route through which experimental data are processed to become information, d) comprehend the nature and source of measurement errors, and e) endure the highest degree of safety.

During school-laboratory practice, most of the time and effort is usually spent to ensure correct operation lab instruments, flawless data taking, and recording, whereas scant time is spent on reflection about the experiment itself. Moreover, in such cases, little attention is paid in observing the phenomenon as it develops, thereby reducing the educational gain of the whole process to being just partially acceptable, or even marginal.

Searching for a way out of this predicament, some researchers consider [33] that the combined use of sensors and ICT in data taking could offer significant help. Time spent in non-creative routine work is reduced, allowing increased opportunities for interaction between teacher and students or between students themselves.

It should be noted here that the use of ICT-based measurement sensors and digital data-collection has a significant additional educational advantage, in that it helps students gain the appropriate experimental and ICT-related dexterities. Such experience is invaluable for their future lives, and can only be gained as such by persistent and hard work. Overall, heat transfer phenomena are an ideal introduction of the use of sensors in a school lab environment, where ICT-systems are also utilized.

The use of sensors, automated data loggers and suitable software, allows the design of experimental setups that promote student concentration on the overall appreciation of the physical process in its entirety, potentially improving students understanding. Main benefits from that change include allowing more time to students to reflect and discuss the phenomena observed amongst themselves, the teacher intervening to answer to student's queries and (at a more advanced level) perhaps discuss what students initially expected that the measurements would show, and whether or not their expectations were fulfilled and if not why. Side benefits would include (at times of limited space or budget) the possibility of a larger number of students using the same experimental apparatus (i.e. while the previous group discussed with the teacher).

Heat transfer experiments represent an ideal first use of data-logger methods in school-lab environments. Despite the simplicity of the sensors (being simple thermocouples), the necessity of device calibration and the need for rapid data-taking and recording, present far too high a workload to the students, when done conventionally. It is no wonder, therefore, that most educators choose not to offer such "heat transfer" lab experiment at school, despite the fact that it represents a large part of the theoretical syllabus for many Vocational Schools specialties: they know by experience that students gain only marginally by it, when done conventionally.

Based on the above, the educational hypothesis of the present educational research was as follows. "Students' active involvement in the setting up of a simply and carefully designed experimental setup, which uses sensors in combination with a suitable software and experimenting with it, helps them improve their understanding regarding the concept of heat transfer phenomena, as opposed to those students who simply experimented with the same setup".

IV. THE RESEARCH

The present research was carried out during the 2007-2009 school year. A sample of 122 Vocational School students, aged from 16 to 20 years, studying vocational-engineering to become mechanics, participated in the research. These were divided in two groups, the experimental one with 64 students, and the control group consisting of 58 students. Students of the experimental group were asked to design, create, calibrate, set-up, and subsequently use the experiment. Students belonging to the control group refrained from any creative design and just used the experimental setup to perform the lab-experiment. Following a mixed research methodology design, both a questionnaire and extensive personal interviews were used to collect the research data.

The research was carried out in four successive phases of instructional intervention, which entailed a total of six hours of instruction per student. Constructivist learning techniques were used throughout this teaching. An additional hour was devoted to the detection of possible changes in students' initial ideas on heat transfer phenomena (this representing the fifth phase). More specifically:

1st Phase of intervention (1 hour)

Students were given a questionnaire through which their initial ideas relating to thermal conductivity phenomena were detected. This pre-test constituted the initial data-taking for the experiment. This was subsequently followed by oral interviews, during which each student was asked to explain and expand on his ideas for each of the physical processes. The purpose was to ensure that the researcher understood each student's ideas, as well as to allow the student time to expand his thinking on heat transport and other associated phenomena. This way, the cognitive clash that would follow as a result of the next phases would become all the more acute, to the benefit of the student.

2nd Phase of intervention (1 hour)

An explanation of what was to be measured and why was given by the teacher-researcher, as well as the way the heat-sensors operate. Moreover, the students of the experimental group were asked to suggest ways of creating parts of the experimental setup so as to effect such measurements. These included the exact locations of the metal bars that were to be used for measurement, and the way to transfer the data taken to the lab-PC. Solutions were proposed by the students of the experimental group themselves, after some collaboration between members of the working-group consisting of 4-5 students at a time. In contrast, students of the control group were given an explanation of the function of the various components of the experiment by the teacher. For both experimental and control groups, the way the data were processed and the interpretation of the resulting information was explained in some detail by the teacher.

3rd Phase of intervention (3 hours)

It was carried out by working-groups of four or five students at a time, each of which was given a different metal bar to study. The students experimented, processed their measurements, and presented their results. The students of the experimental group, were divided in working-groups of 4 to 5, after having being given a short instruction by the researchers, succeeded in creating parts of the experimental setup, utilizing their lab equipment. The students of the control group simply used the experimental setup, but they also worked in working-groups of 4 to 5 people. All experimented on different metal bars, and all recorded the data, processed them, and presented their results.

4th Phase of intervention (1 hour)

The students gave individual oral interviews to the researchers. An open discussion followed, during which students' ideas were recorded. During the evaluation process, student's opinion on the total experimental teaching process was also detected and recorded.

5th Phase of intervention (1 hour)

A week later, the same students were asked to fill the initial questionnaire again, in order to detect any changes to their ideas as regards the heat transfer phenomena. This was the post-test and concluded the data-taking.

V. DATA ANALYSIS

Every study (or every measurement, or every evaluation) involves, in general, a number of experimental errors. Such errors can be finally folded into a single numerical value (one for every data point), called measurement errors. Every experimental point measured is (in general) only valid within the limits of the experimental errors. This is true for every experimental study. While during the data-taking phase of the present experiment an emphasis was paid in minimising biases and avoiding large systematic errors, during the data analysis an effort was paid into evaluating these, which after due consideration were set at 3.0% flat, a figure which is comparable with all our statistical errors, and not dominated by them. All relevant statistics were calculated using specially constructed software, interfaced with a popular computational and plotting package. The statistical error was calculated for each and every point of the data-set taken, because this is both a function of the sample taken as well as the actual number of students selecting this answer represented by the data-point. The statistical variance was computed and the Bessel-corrected standard deviation was calculated for all data points presented. The total experimental error was then calculated by adding in quadrature the systematic with the statistical errors, these two errors being by definition independent.

VI. RESULTS

The following figures show the resulting percentages obtained for the eight questions presented herein. The experimental group results are shown side by side with those obtained from the control group, whereas each histogram shows both the pre-test and the post-test results so as comparisons can be made directly. The results depict the percentage of students whose answer falls in each of the 4 categories, respectively: Correct answer, Partially correct answer, Wrong answer, I don't know – No answer given. Error bars on either side of all experimental points presented correspond to one standard deviation for the total experimental errors (both statistical and systematic) and are computed for each data-point, individually after due consideration for possible biases. The difference in percentage between Green Squares (i.e. pre-test) and Blue Triangles (i.e. post-test) can be attributed to the effect of the teaching.

A. Question 1: What is heat?

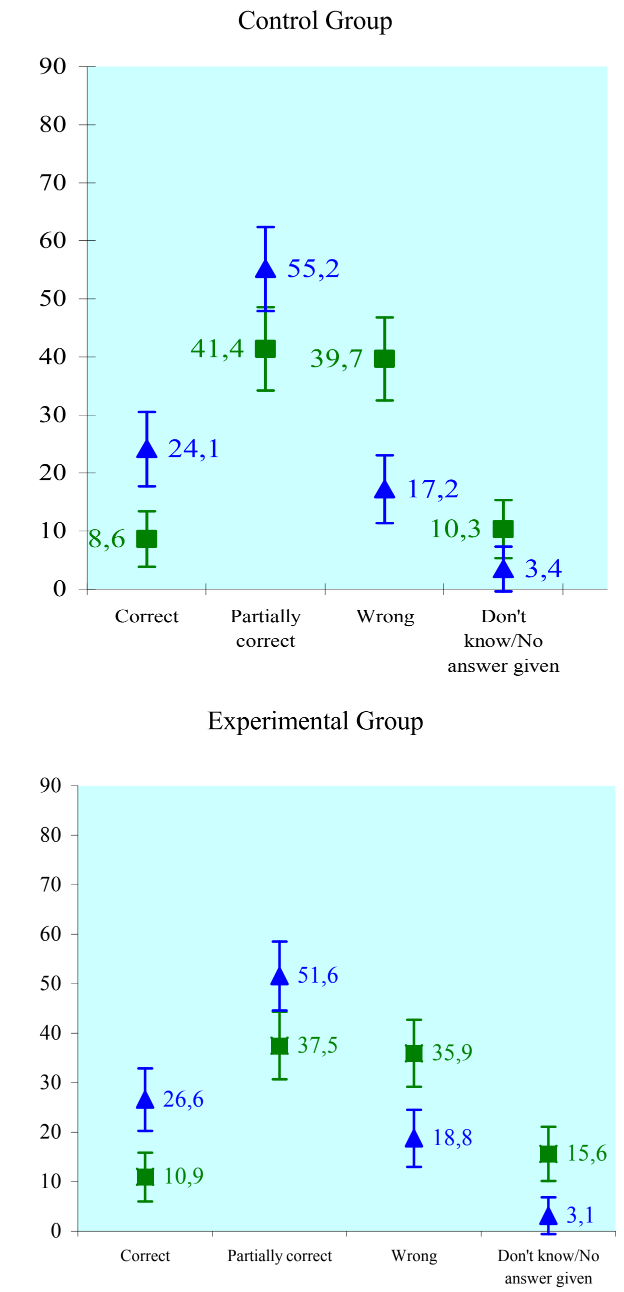


Figure 1. What is heat?

Overall, the percentage of the students of the experimental group, who either answered correctly or gave partially correct answers was 48.4% (±7.0%) during the pre-test, while at the post-test it increased considerably, that is to 78.2% (±6.0%). The percentage of the control group was 50.0% (±7.3%) and 79.3% (±6.1%) respectively. No considerable difference between the two groups can be observed.

B. Question 2: What is the meaning of heat transfer?

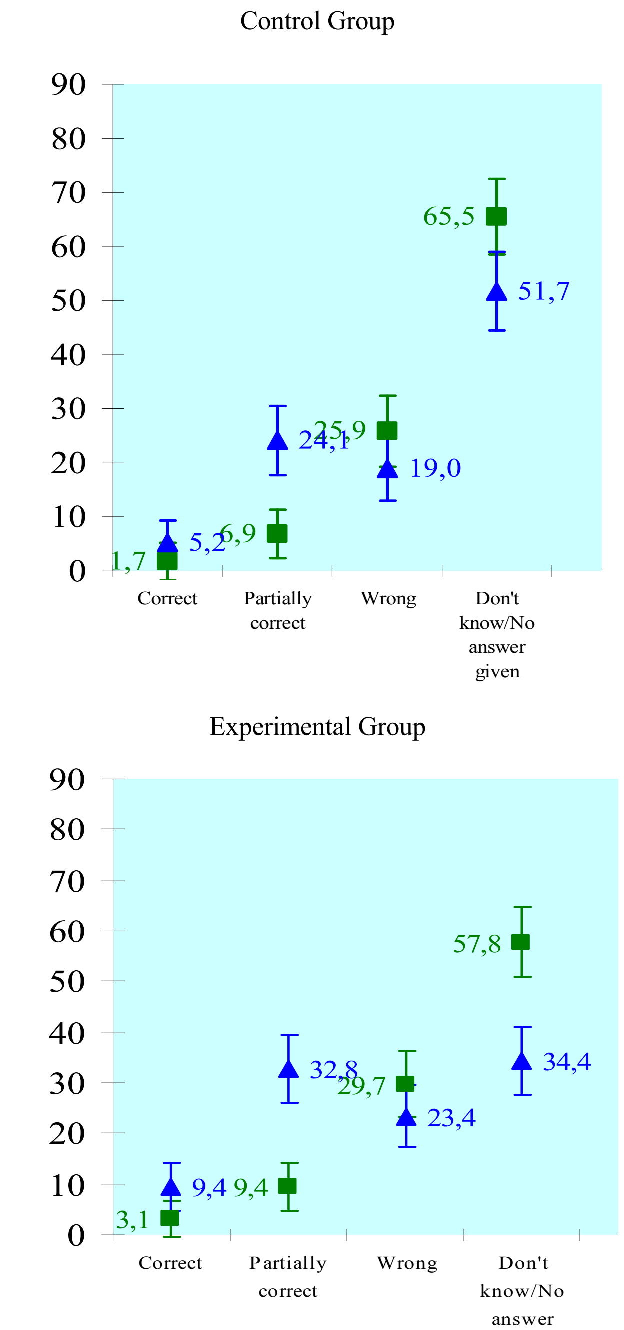
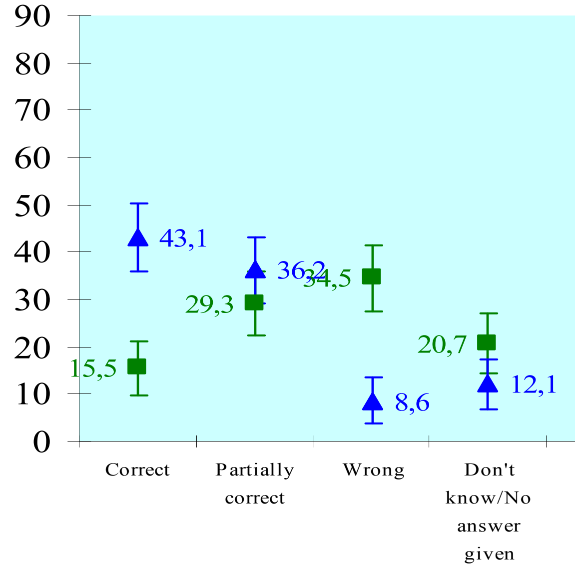


Figure 2. What is the meaning of heat flow?

Overall, the percentage of the students of the experimental group, who either answered correctly or gave partially correct answers was 12.5% (±5.1%) during the pre-test, while at the post-test this increased to 42.2% (±6.9%). The percentage of the control group was 8.6% (±4.8%) and 29.3% (±6.7%) respectively. There is (just) some difference to be observed between the two groups, albeit on marginal side.

C. Question 3: What is temperature?

Control Group



Experimental Group

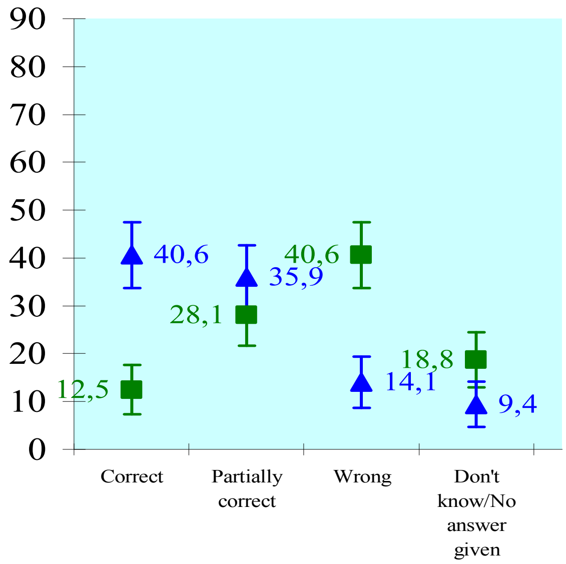
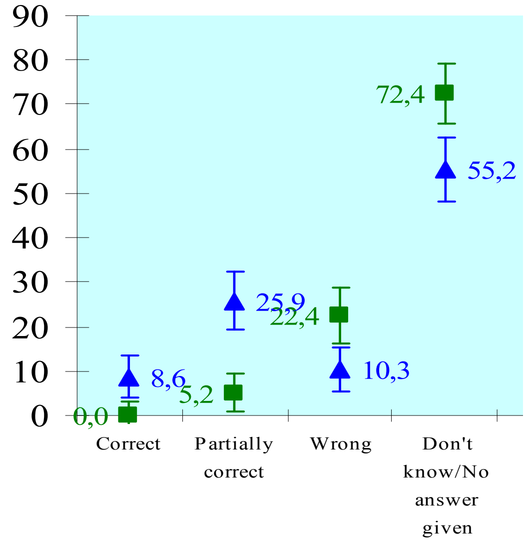


Figure 3. What is temperature?

Overall, the percentage of the students of the experimental group, who either answered correctly or gave partially correct answers was 40.6% (±6.9%) during the pre-test, while at the post-test it increased to 76.6% (±6.1%). The percentage of the control group was 44.8% (±7.2%) and 79.3% (±6.1%) respectively. No considerable difference between the two groups can be observed.

D. Question 4: The atom structure of the metals

Control Group



Experimental Group

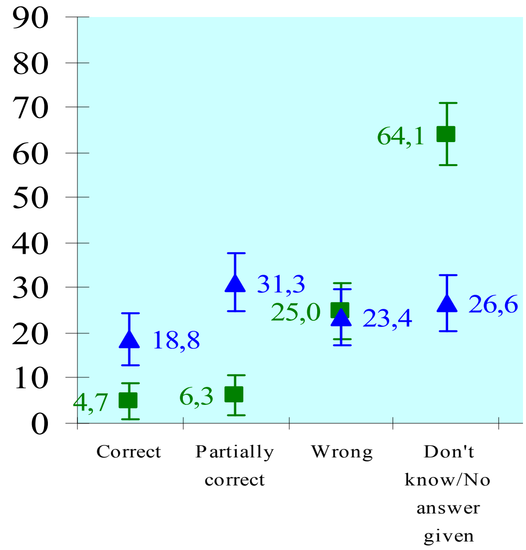


Figure 4. Describe the structure of a metal

Overall, the percentage of the students of the experimental group, who either answered correctly or gave partially correct answers was 11.0% (±4.9%) during the pre-test, while at the post-test it increased to 50.1% (±7.0%). The percentage of the control group was 5.2% (±4.2%) and 34.5% (±7.0%) respectively. There is a considerable difference between the two groups to be observed.

E. Question 5: The operation of an incandescent lamp

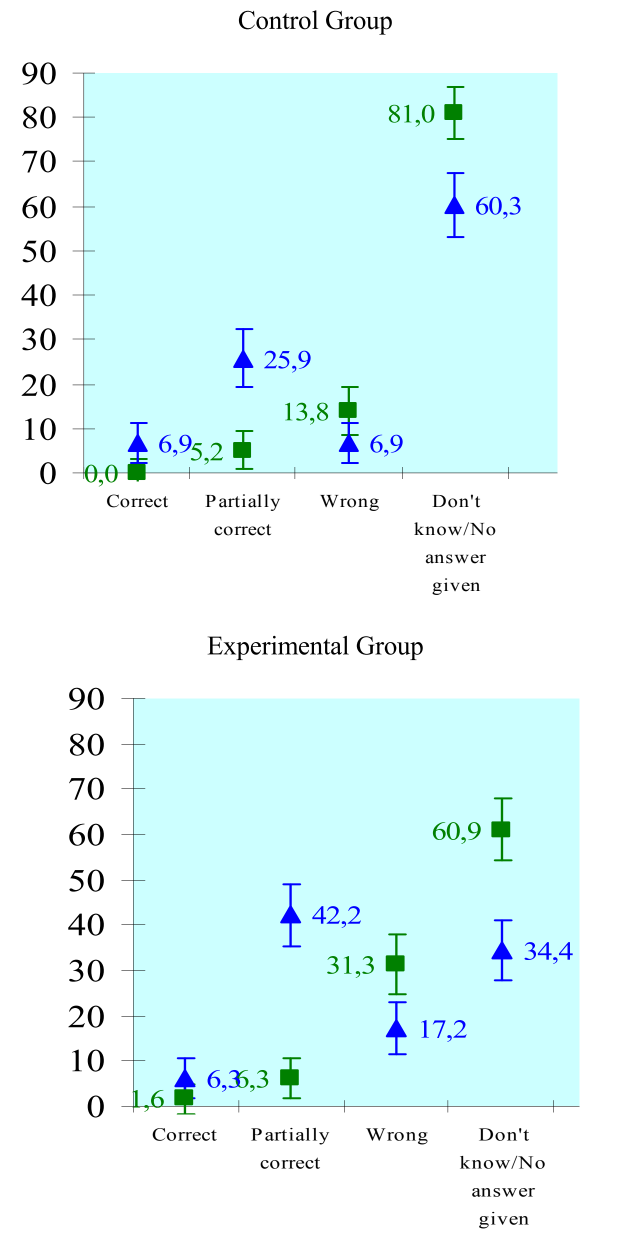


Figure 5. Incandescent lamp operation

Overall, the percentage of the students of the experimental group, who either answered correctly or gave partially correct answers was 7.9% (±4.5%) during the pre-test, while at the post-test it increased to 48.5% (±7.0%). The percentage of the control group was 5.2% (±5.2%) and 32.8% (±6.9%) respectively. A noticeable difference between the two groups can, therefore be claimed.

F. Question 6: The functioning of an electric cooker

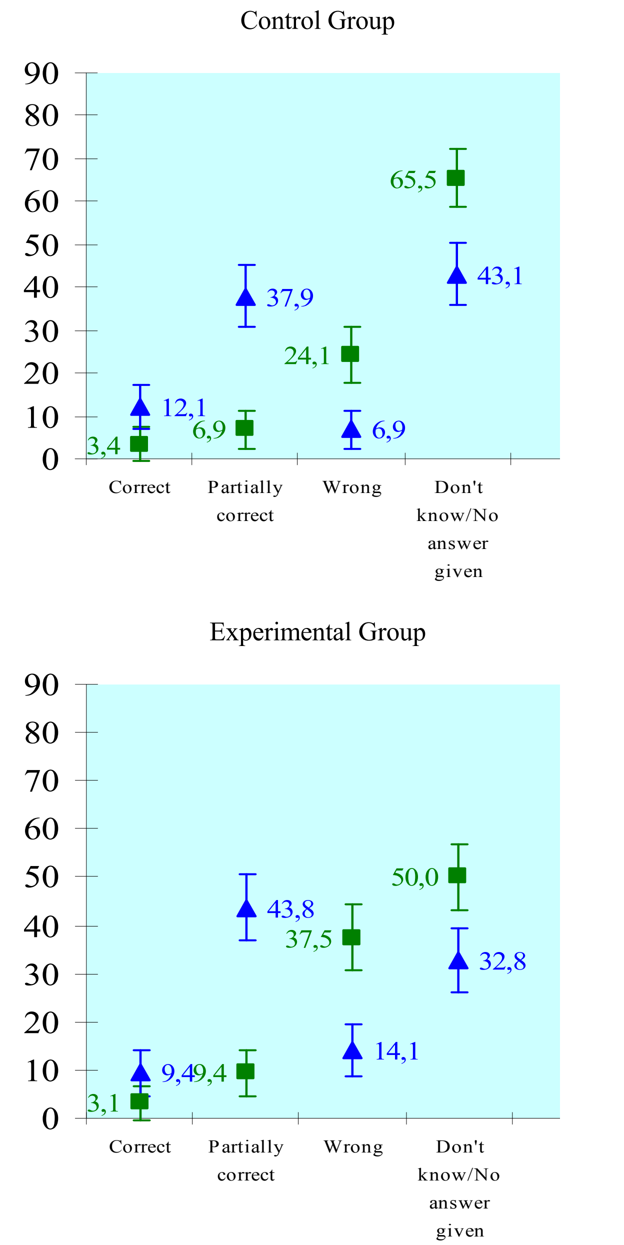


Figure 6. Electric cooker function

Overall, the percentage of the students of the experimental group, who either answered correctly or gave partially correct answers was 12.5% (±5.1%) during the pre-test, while at the post-test it increased to 53.2% (±7.0%). The percentage of the control group was 10.3% (±5.0%) and 50.0% (±7.3%) respectively. No considerable difference between the two groups can be observed.

G. *Question 7: The functioning of a microwave oven*

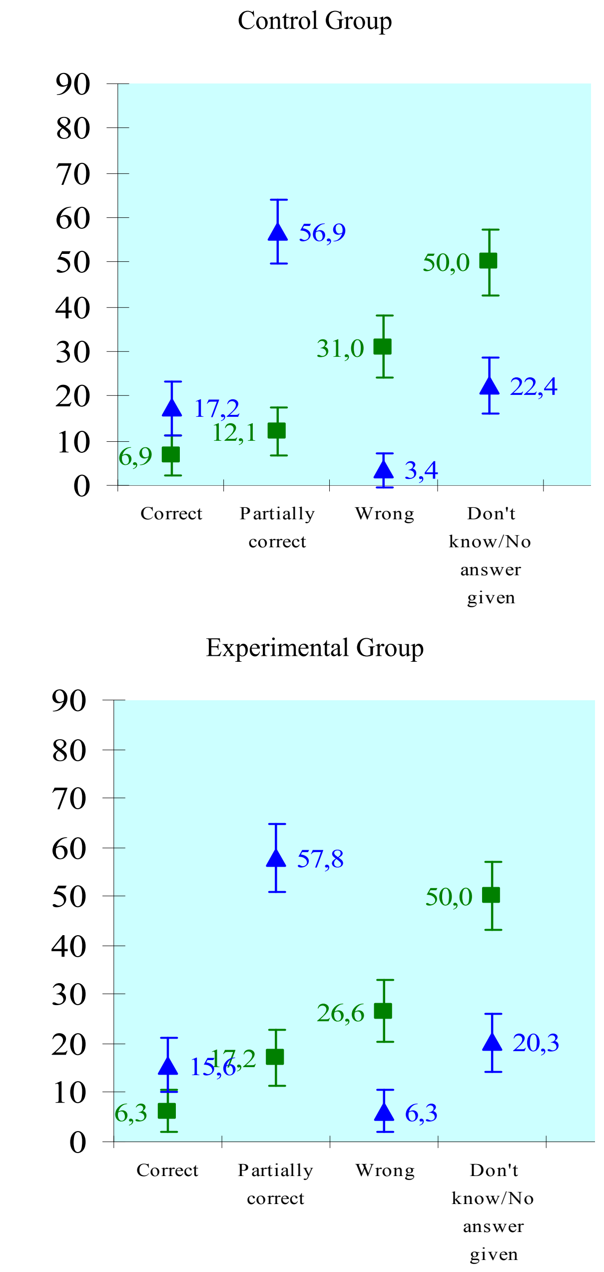


Figure 7. Microwave oven function

Overall, the percentage of the students of the experimental group, who either answered correctly or gave partially correct answers was 23.5% (±6.1%) during the pre-test, while at the post-test it increased to 73.4% (±6.3%). The percentage of the control group was 19.0% (±6.0%) and 74.1% (±6.5%) respectively. There was no considerable difference found, between the two groups.

H. *Question 8: Wind cools down warm objects*

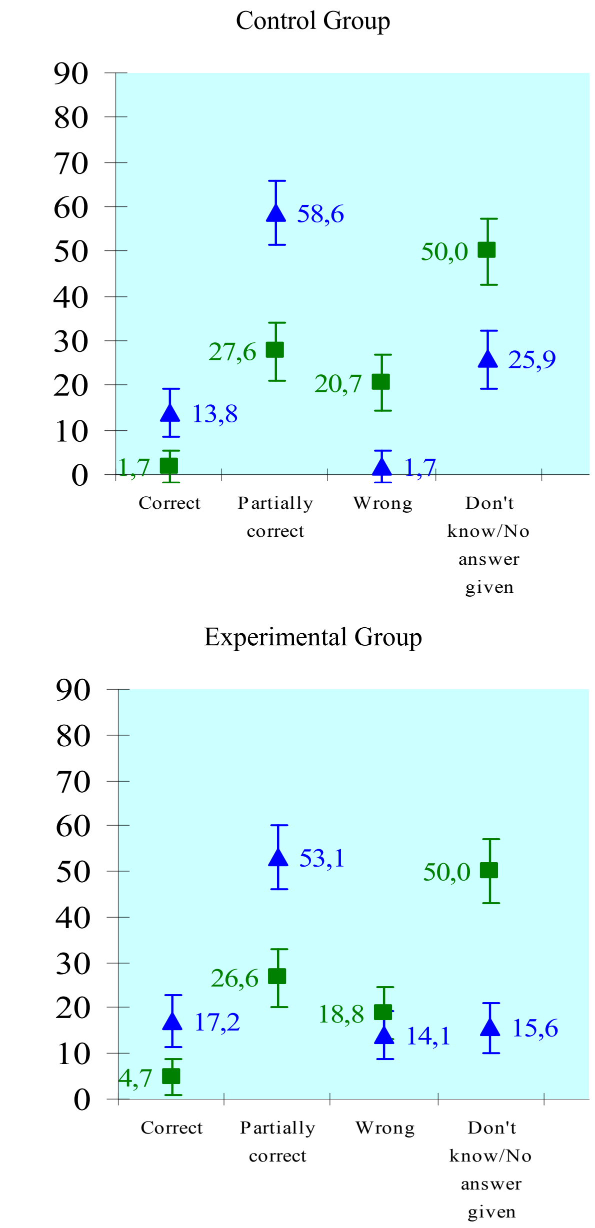


Figure 8. Wind cools down warm objects

Overall, the percentage of the students of the experimental group, who either answered correctly or gave partially correct answers was 31.3% (±6.6%) during the pre-test, while at the post-test it increased at 70.3% (±6.5%). The percentage of the control group was 29.3% (±6.7%) and 72.4% (±6.6%) respectively. Therefore, no considerable difference between the two groups can be observed.

VII. DISCUSSION AND CONCLUSIONS

The analysis of students' answers, before the experimental-instructive intervention, showed that a large percentage of them had rather confused ideas about the concepts of heat and temperature, the structure of metals as well as simple heat transfer phenomena.

The researchers found that students approached the phenomena verbally and superficially, precluding any hope of deeper scientific understanding. The research hypothesis was that: "if students are given the chance to use their own aptitude in designing and creating and calibrating simple experimental setups, they are led to creative and productive thinking". The hope was that students would cooperate with one another harmoniously, and that they would come up with original (for them, that is) solutions, and will improve their dexterities, as well as their ability to present and control hypothetical reasoning.

It was observed that students participated actively and with great interest in the experimental process, with the feeling that as they were creators themselves, and also that they did control more effectively the process of the experimental procedures, as opposed to those students who simply use experiments already set-up. This led them into developing an intense research disposition with a great number of useful and productive queries. This resulted in the fulfillment of the instructive aims of the experimental setup students, activating their inner creativity, and converting them to "active researchers" rather than passive observers. Moreover, the use of the sensor and the relevant software enhanced the educational effectiveness of the school lab, releasing students from the stress of the correct experimental data taking and recording, giving them the possibility to focus their attention to the phenomenon as this develops in time. This situation was recorded clearly in students' answers. The comparison between the two groups showed that the students of the experimental group had given a larger percentage of either right or partially right answers than the students of the control group, in the questions which were related to their setting up. No significant change was observed for the rest of the questions.

More specifically, the students of the experimental group, managed to have a percentage of correct answers higher than those of the control group on 3 occasions: a) in the question "what is the meaning of heat flow?" b) in the question "what is the atom structure of metals?" and c) in the question "what is the operation of the incandescent lamp?". For the rest of the questions a small, non-significant differentiation of ±3% was found.

By the end of the experimental process, students' interviews revealed that the reasons for this differentiation were: (a) "….cutting and processing the metal rods and the insulating their inner sides…." , which differentiated their views about the structure of metals. Also, (b) "….the marking the specific places and the attachment of the sensors on the metal rods….." in specific places, which they themselves suggested and carried out, which differentiated their views about the heat flow along the metal bar. And also (c) "…..the constant use of the incandescent lamp as a basic heat source, attached at the one end of the metal bar…." differentiated their views on the way an incandescent lamp operated.

Finally, the researchers noted that throughout the experimental process, the students participated actively and with interest, they found the questionnaire relatively easy to understand, comprehended the constructivist learning process, and finally they concluded quite happily that software was a worthwhile integral part of the learning process.

The conclusion is that there is a considerable improvement to be gained through the combination of ICT technologies and sensor and data-logger based school experiments. The main reason for this improvement can be attributed to the considerable time and effort saved in the course of data-taking and data-analysis, as well as in dealing with associated trivial problems, the workload form all these being responsible for the detriment of real understanding, as it effectively masks-out the "overall experimental didactic message".

Are the present findings relevant to all types of secondary schools? A main concern that would hinder the implementation of the proposed procedure at a non-vocational (general-purpose) secondary school would be a possible lack of special lab equipment, and possible lack of space that is necessary for the setting up of parts of the experimental device, as well as the conceivable lack of suitable helping staff at the computer-lab to ensure a safe technical support for the students. If such considerations are fulfilled, there seems little (if any) reason to believe that the present findings are not universally applicable.

Could we reasonably assume that concepts other that heat-transfer could be taught using similar techniques utilizing sensors and ICT? We would like to point out that all the questions posed to students were fairly general questions testing their understanding of fundamental Physics concepts and they are related to the general science teaching content, albeit indirectly. It should also be noted that all the observations mentioned in the present discussion are those exceeding the total experimental measurement errors – so one can be more or less certain about the conclusions. On the basis of the two aforementioned points, we can safely conclude that the present research effort shows a significant improvement in students' understanding of those physics concepts which are in some way related to heat transfer phenomena – but not necessarily strictly limited to them (e.g. atom structure of metals). This improvement is attributed to students' involvement with the design, creation, and calibration of an experimental set-up and the use of ICT-systems in the collection, transfer, and processing of the experimental data and the presentation the resulting information, and as such can be used to teach other science concepts using sensors and ICT.

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