INVESTIGATING THE USE OF SIMULATED LABORATORY FOR TEACHING ASPECTS OF CALORIMETRY TO SECONDARY EDUCATION STUDENTS

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ABSTRACT
Content analysis of textbooks and of research - based innovative approaches suggests that there is not a widely accepted negotiation of the order in which factors that are expressed in relation $\boldsymbol{Q = m \cdot c \cdot \Delta\theta}$ should be examined. The treatment of heating time and final temperature is also important variables that deserve investigation. In this context, we designed visual experiments engaging students in investigating the change of temperature ($\boldsymbol{\Delta\theta}$), mass ($\boldsymbol{m}$), and material ($\boldsymbol{c}$) together with using bodies acquiring the same final temperature after heating. The simulated visual laboratory used in the present study is a micro-world for the teaching of thermal phenomena. The analysis of the data provided encouraging outcomes. It appears that the use of a dynamic system where the different phases of the experiment evolution can be paused and restarted offered opportunities for innovative negotiation of the relation of calorimetry. Moreover, the facility for changing parameters and seeing the readouts quickly permitted students to experiment with different initial temperatures and promoted a holistic approach to the experimental process, facilitating the linking of theory with experimental results by the students.

KEYWORDS
Simulated Visual Laboratory, Calorimetry, student's ideas

INTRODUCTION

Despite the numerous studies regarding the concepts in thermal phenomena, much less attention was given to Calorimetry. Most of the researches focus on student's conceptions about Heat and Temperature (Driver et al. 1994). Research findings point out that students can hardly distinguish the concept of 'heat' from 'temperature'. In many cases, students cannot recognize the *intensive* character of temperature, and in their arguments, they use *extensive* properties for temperature, as if they were referring to heat (Kesidou et al. 1995). When addressing temperature, students usually refer to it, as to the measurement of heat (Tiberghien 1983).

Calorimetry is a topic that connects heat with temperature, concepts that students do hardly distinguish, providing the framework for examining the factors that affect the amount of heat transferred for a specific change of temperature. Specifically, in the relation of calorimetry, $\boldsymbol{Q = m \cdot c \cdot \Delta\theta}$, $\boldsymbol{Q}$ is the transferred thermal energy, $\boldsymbol{m}$ is the *mass* of the body that absorbs the heat, $\boldsymbol{c}$ is the specific heat of the body and $\boldsymbol{\Delta\theta}$ is its *change of temperature*. Though some researchers (Rosenquist et al. 1982, Linn & Songer 1991) have argued that the analogy between the heat and the change of temperature in the relation of calorimetry could lead to enhancing the non-distinction of heat and temperature in students' minds, we believe that it would be very advantageous if we address calorimetry in a *dynamic system*. In other words, if students have the option to explore a dynamic system, where heat given into the system can be calculated and resulting changes in temperature can be recorded, and if, in addition, system components can be easily modified in a simple, interactive and dynamic way, then we believe that there would be a great chance to address the conceptual difficulties in calorimetry. Besides students may gain a deeper understanding on the relation between heat and temperature.

Computer technology of today can give us systems and processes of automated measurements with Microcomputer Based Laboratory (MBL), which have been proved for years effective enough for fast data logging and the resulting simultaneous graphs has been proved very efficient for educational use (Newton 1998). Today's sensor technology can provide us with adequate sensors which can monitor both the temperature and the heat transferred in a simple to use and accurate way, and could be proved useful in the study of calorimetry. Though we do not argue against the generally accepted and proved effectiveness of the MBL experiments (Thornton 1999), we believe that dynamic systems can be studied more efficiently in a simulated lab environment, where students can easily setup the experiment, repeat it numerous times upon change of initial conditions and parameters at a fraction of time and effort. Last but not least, the option to pause and restart the experiment evolution at critical points, can make the Simulated Visual Laboratory (SVL) a valuable tool for the study of dynamic systems, and furthermore, as a thinking sketchpad for students to confront their ideas and to reconsider their initial thoughts and predictions in an interactive way.

In this work we developed and applied in an exploratory study an intervention of the relation of calorimetry in a dynamic system, with the help of the SVL, where students' learning difficulties were taken into account. The features of the SVL gave us the chance to design a holistic approach of the relation of calorimetry. In the first part of the present paper, we present an overview of the didactic approaches on the relation of calorimetry as appear either in Greek textbooks or researchers' works. In the second part of the paper, we proceed with the research design and the description of the intervention developed in an iterative way with student's conceptual evolution.

INSPECTION OF DIDACTIC APPROACHES ON THE RELATION OF CALORIMETRY

A. Approaches of calorimetry in textbooks and lab books

In Greece, two years ago, there were two textbooks and lab books (Karapanagiotis et al. 1998, Antoniou et al. 2000) for teaching Physics of the compulsory education in Secondary School. Now, only one of the two books remains, the one of Antoniou et al. (2000). In the present study, both textbooks and lab books were studied. The study of the didactic approaches of textbooks took place with reference to the order that factors should be dealt with, the variance or not of heat rate and the way that heating is handled, that is, if the time of heating is stable and the change of temperature is calculated or if the final temperature which the bodies acquire is the same and the time of heating is measured.

Details for the study have been reported elsewhere (Petridou 2003, Petridou et al. 2005). From our findings, we conclude that there is no preferred order in the discussion of the $\boldsymbol{m} - \boldsymbol{c} - \boldsymbol{\Delta\theta}$ factors. Initially, when calorimetry is introduced, the order $\boldsymbol{m} - \boldsymbol{\Delta\theta} - \boldsymbol{c}$ is adopted in both textbooks. When the subject is discussed further on, the order changes into $\boldsymbol{\Delta\theta} - \boldsymbol{m} - \boldsymbol{c}$**.** In both textbooks, examples of illustrated experiments are presented to support the theoretical discussion. In all cases the *heating rate* is not constant. In a typical illustrated experiment, which appears in both textbooks, equal amounts of the same material (water) are heated up for the same time at different heating rates. The resulting change in temperature is discussed in the text. In one of the textbooks (Antoniou et al. 2000), the illustrated experiment is extended further, taking into account different *materials* (water / olive oil) or different amounts of the same material, to address the issues of *mass* or *specific heat* in calorimetry.

While in textbooks the three factors ($\boldsymbol{m}$, $\boldsymbol{\Delta\theta}$, $\boldsymbol{c}$) are studied with variable heating rate in the illustrated experiments, this approach is not consistent with the lab-book experiments. Actually, in the lab-book experiments the supplied heat is always kept at a constant rate. Some intuitive experimental tricks can be found in the lab-books, like the calculation of transferred heat $\boldsymbol{Q}$, by the $\boldsymbol{m \cdot \Delta\theta}$ product in water (Petridou et al. 2005) or the mass vs. heating time graph to evaluate specific heat (Antoniou et al. 2000). However, neither of these tricks is in close with the way that the subject is dealt in textbooks.

B. Research based approaches on calorimetry

Certain researchers made various proposals for studying calorimetry. Rosenquist et al. (1982) and Linn & Songer (1991) studied the factors of the relation of calorimetry through thermal equilibrium. For example, Rosenquist et al. (1982) studied the change of temperature of bodies, which interact thermally and the amounts of heat that are transferred between different amounts and materials. Bisdikian (2000) approaches the relation of calorimetry through heating. Initially, the effect of the amount of heat absorbed by the body to its *change of temperature* is studied. After that the effect of *mass* and *material* is studied in the temperature increase of the body for a specific time when the heat rate of the heating source is constant.

Our overview on the didactic approaches, as appear either in textbooks or in research work, shows that maybe there is not a unanimous approach to the factors of the relation of calorimetry. Besides, what matters is the maintenance of the heating rate constant or not and the way that heating is studied, that is if the time of heating is stable and change in temperature is calculated or if the final temperature that the body acquires is the same and the time of heating is calculated. Special attention is needed in the way that the *change of temperature* is handled since there is a danger of emphasizing the analogy between $\boldsymbol{Q}$ and $\boldsymbol{\Delta\theta}$ having as a result the maintenance or even the reinforcement of the confusion between heat and temperature in students' minds. We could overcome this danger through teaching the relation of calorimetry, in a dynamic system, which would make learning more effective.

RESEARCH DESIGN

In the present study we followed the methodology of "teaching experiments" for the development of intervention (Steffe & D´ Ambrosio 1996). According to this method, we developed and applied successive interventions in small groups of students, which aimed at revealing the crucial points so that the teaching should be adapted to students' learning difficulties (Petridou et al. 2005). Four teaching interventions, each one lasting two didactic hours, were developed and applied at the compulsory lower high school. Our sample was ten students (14 years old). The interventions were applied to groups of students (pairs) and were based on an open learning environment, which helps the implementation of new approaches to heat phenomena with the possibility of flexible adaptation, of ThermoLab, a simulated visual Laboratory for the study of Thermal Phenomena (Psillos et al. 2000).

The outcomes came from the analysis of pre- and post-tests, given prior and after the interventions, students' written prediction before the execution of the experiments and interviews – discussions between students and teacher about clarifying their responses. In both pre- as well in post-tests three qualitative tasks were given to students. In the first task students were asked to predict whether they would need the same or different amount of time for heating milk and water of the same quantity and for the same change of temperature. In the second task students' predictions were required for the factor of *mass* where different amounts of water were heated and in the third task students' predictions were required when equal amounts of water of different initial temperature were heated. Pre- and post-tests were identical, so we could directly compare the students' conceptual level before and after the intervention. We consider that the expression of students' ideas as well as the analysis of the data are complex procedures which are characterized for their dynamics and as a result based only on written tests are not adequate enough to determine students' conceptual evolution. So, it was considered important for a deeper analysis to videotape all four interventions, transcribe and analyse student teacher interactions.

The interventions took place with the help of specially developed worksheets whose structure included prediction of each activity by the students, execution of the experiment, explanation, and comparison of experimental data to their initial predictions (White & Gunstone 1992, Psillos et al. 2002). At the end, students were given, also, a question to answer, similar to that executed in the experiment.

INTERVENTION WITH THE USE OF THE SIMULATED VISUAL LABORATORY

Based on students' conceptions and the results of successive teaching experiments, we gradually developed the didactical intervention (Petridou et al. 2005). The successive teaching experiments showed that students faced learning difficulties with *mass*, as it was the factor of the relation of calorimetry where most students' intuitive ideas came to light during the discussions between the teacher and the students. Consequently, we decided that the order that the quantities of the relation of calorimetry should be taught is: ***Δθ***, ***m***, ***c***. This is in line with teaching of concepts first that are easier for students to understand and then those that complicate them as proposed by Brown & Clement (1992).

The intervention consisted of three visual experiments for the study of each factor (***Δθ***, ***m***, ***c***) when bodies were heated with Bunsen burners of constant heat rate. Specifically, for the study of ***Δθ***, same quantities of water were heated on same burners acquiring the same final temperature while having different initial ones. In the second of the experiments, students examine the influence of *mass*; different amounts of water were heated on identical heaters, until the *same* change in temperature was obtained (same initial and final temperatures). In the third of the experiments, students explore the influence of *material* in calorimetry; different liquids (water and olive oil) of the same mass were heated up. Similar to the second experiment, liquids were heated up on identical heaters, until the *same* change in temperature was obtained. In all three experiments the amount of heat required, was calculated as the product of the heating rate by the heating time.

The SVL allowed us to approach the relation of calorimetry through a dynamic system in which the student can setup the experiment by using measurement instruments and devices, temporarily pause and restart the experiments, bring them back to their initial state and study the experimental data through real time graphs (Psillos et al. 2000, Hatzikraniotis et al. 2001). The flexibility of "freezing" (pausing) the evolution of the experiment and restarting it without loosing the data, the real time graph, the capability for negotiation of the amount of heat, the parameterization and the speedup of the running time of the experiments were features of the SVL that helped us approach the relation of calorimetry in a holistic and innovative way.

We took notice of the way of negotiation of the factor of the *change of temperature* because of the analogy between the heat and the change of temperature in calorimetry, which, as known, might reinforce the confusion of the concepts. It was decided that the amount of heat absorbed during heating should be calculated when two identical liquids of the same mass acquire the same final temperature having a different initial one. Our choice that bodies acquire the same final temperature helped us work with the students' idea that temperature is the measure of heat. When students saw that two bodies acquired the same final temperature they considered that bodies had absorbed the same amount of heat. So, by observing in the experiments that bodies absorbed different amounts of heat in order to reach the same final temperature, they were helped to distinguish the concepts heat – temperature. In this way the analogy between heat and the change of temperature was studied without the risk of reinforcing the confusion of the concepts heat and temperature. The change of temperature for all three factors (***Δθ***, ***m***, ***c***) was faced so that the bodies heated reach the same final temperature (figures 1a and 1b) and without calculating the change of temperature for the same heating time.

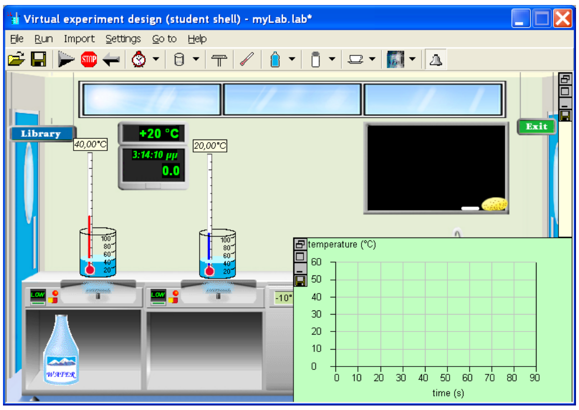

Figure 1a. initial conditions

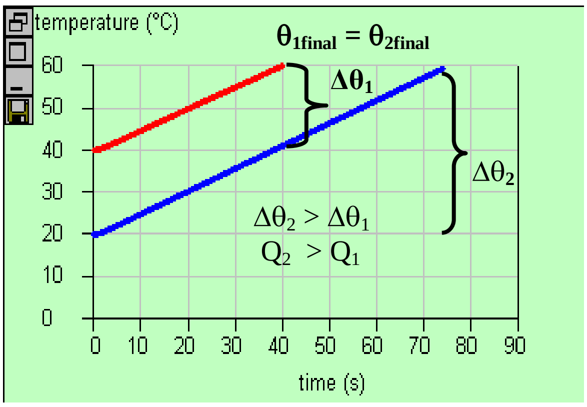

Figure 1b. final graph

The “freezing” of the running (evolution) of experiments at appropriate times, i.e. when one of the two bodies first reached a predetermined temperature, reinforced the special negotiation of the final temperature as discussed above. “Freezing” the experiment gave students the needed time to think on their ideas against the experimental data.

RESULTS

The learning results were extracted from the analysis and the comparison of the written pre- and post-tests, the analysis of the discussion between the teacher and the students on their predictions in the worksheets before and after each experimental task, as well as from video analysis of the interventions.

The analysis of pre-tests shows that several students answer incorrectly when asked on the influence of *mass* or of *material*, and fewer answer incorrectly regarding the *change in temperature*. The learning results were encouraging as the majority of students in post-tests addressed after the teaching procedure, recognized the role of each factor in the amount of heat that was required in the bodies’ heating. Despite the positive data from the written pre- and post-tests, discussions between the teacher and the students were far more enlightening and formed a more complete picture of students’ conceptual evolution. The discussion based on students’ written predictions before and after each experiment, during the intervention, allowed students to reflect on their ideas. Students used intuitive ideas to justify their answers. The conceptual evolution of one representative group consisted of two students is presented below for each factor of the relation of calorimetry.

- **The influence of the change of temperature ($\Delta\theta$)**

In their predictions prior to the first experiment related to the *change in temperature*, students were asked if the heating time and the amount of heat is the same or different when two equal quantities of water of different initial temperature acquire the same final temperature. Students answer correctly about the time, but in an alternative way about the amount of heat absorbed.

Extracts of a typical discussion between the teacher and the group of students while they were performing their experiments is presented below:
Teacher (T): what did you answer in the prediction?
Student 1 (S1): that both beakers with water will take the same amount of heat, but because of their different initial temperature they will need different time to reach the same final temperature.
T: what about you? (The teacher addresses the other student of the group)
S2: I agree. They will absorb the same amount of heat because they are on same Bunsen burners.
S1: yes, I have also written that they will absorb the same amount of heat as they are on the same Bunsen burners.

Such students’ responses are in agreement with their responses in the pre-test. This suggests that they perceive that water with the lower initial temperature will need different heating time from the one with the higher initial temperature. However, they argue that the same amount of heat will be absorbed from the bodies as they are on same Bunsen burners. From students’ responses it seems that they do not seem to make a clear distinction between the heat flow and the amount of heat absorbed.

After the experiment both students answer correctly. In the task given to them we had deliberately changed water (as was in their experiment) to olive oil. They were asked if the heating time and the amount of heat is the same or different when two equal quantities of olive oil of different initial temperature acquire the same final temperature:

T: what did you answer?
S1: beakers with olive oil will be heated in different time.
T: what about you?
S2: I agree.

T: if I asked (the teacher addresses to S1), *which of the two bodies needs more time to be heated what would you answer?*
S1: the olive oil with the initial temperature of the 30 ^{0}C *needs more time from the one that has initial temperature 40* ^{0}C.
T: in relation to the amount of heat what did you answer?
S1: that the one with the lower initial temperature will absorb greater amount of heat.
S2: I believe the same.

- **The influence of mass (*m*)**

Prior to the second experiment related to the influence of *mass*, students were asked if the heating time and the amount of heat is more, the same or less when different quantities of water are heated for the same temperature change. Both students answered correctly that the different quantities of water would acquire the same final temperature in different time. However, concerning the amount of heat they replied in an alternative way.

In the discussion it was said:
T: what did you answer in the prediction?
S2: that the 100 g of water will reach earlier the 50 ^{0}C *than the 200 g of water.*
T: do you agree? (the teacher addresses to S1).
S1: yes.
T: why did you answer that 100 g will reach earlier the final temperature?
S1: because the smaller mass needs less time to be heated.
S2: I think the same.
T: what did you answer about the heat?
S2: that 200 g will absorb less amount of heat than this of 100 g because the bigger mass needs more time to be heated.

The last phrase leads the teacher to think that the student confused heat flow with amount of heat. She continued the discussion:

S1: I have written that 200 g needs bigger amount of heat than the 100 g.
T: You (the teacher addresses to S2) *say that the bigger mass will absorb less amount of heat because both masses are on the same burners and they give the same amount of heat. Right?*
S2: No!! The burner gave less heat to the bigger mass than to the smaller one.

As discussion goes further, it shows that this student had something else in his mind. If he believed that heat flow is the same with the heat absorbed by the body, he would agree that the same burners gave the same amount of heat to the bodies. Probably, he thinks that the heating time is the same for both bodies, may be influenced by their same final temperature.

Afterwards the other student changes his opinion and the discussion continues:

S1: ……I have changed my initial opinion and I believe something else now.
T: we are hearing you!
S1: now I believe that since the bodies are on the same burners they will absorb the same amount of heat.
T: earlier you told us that the bigger mass would need greater amount of heat. Which do you believe more?
S1: I don't know, now I am confused…………I don't know…………we'll see in the experiment.

It seems that the students meet difficulty in the explanation of the amount of heat. One student believes that the bigger *mass* absorbs less amount of heat and the other student, while in the beginning answers right, during the discussion changes opinion and believes that the same amount of heat is absorbed by both quantities.

After the execution of the experiment both students answer correctly:

T: Well, what did you answer?
S2: that bigger mass absorbs more amount of heat,
S1: and needs more time to be heated

- **The influence of material (c)**

In their predictions before the third experiment that negotiates the factor of *material*, the students were asked if the heating time and the amount of heat is the same or different when equal quantities of water and olive oil are heated for the same increase of temperature. Both students incorrectly believe that water and olive oil will be heated in the same time and will absorb the same amount of heat.

In the discussion they said:
T: what did you answer in the prediction?
S2: that water and olive oil will reach 50 ^{0}*C in the same time.*
T: why?
S2: because they have the same mass.
T: what do you believe? (the teacher addresses the other student)
S1: I have answered that they will be heated in the same time because they have the same mass…the same grammars, but also because they start from the same temperature and acquire the same one.

The students answer wrongly about the heating time and the amount of heat in the factor of *material*. However, it is encouraging that they take into consideration the *mass* and the *change of the temperature* in order to answer. Possibly they took into account knowledge obtained from the previous experiments.

Discussion continues as following:
S1: at first I had answered something else. I thought that they (bodies) would be heated in different amount of time because they are made of different material. I know that olive oil is heated more easily.
S2: I thought about that too, because olive oil gets hotter ……
T: so if we had water and milk you would not have troubled yourselves about the different material?
S1-S2: no, it is the olive oil that gets warm faster.
T: I see. And what about the amount of heat?
S2: they will absorb the same amount of heat since they are on the same Bunsen burners.
S1: yes. Since they have the same mass and the same temperature...

From the discussion we gather that the specific material of olive oil puzzles students because they have the experience of burning themselves from olive oil at everyday life.

After the experiment both students answer correctly.

In the discussion they said:
T: well, what did you answer?
S1: that water and olive oil need different time in order to be heated.
S2: yes
S1: in fact olive oil gets heated faster.
T: good. And if you had water instead of milk?
S1-S2: again in different time
S1: since the material is different.
T: and as far as the amount of heat is concerned?
S2: it is different.
S1: yes.

DISCUSSION - CONCLUSIONS

In the present study, an ICT based laboratory didactical intervention on calorimetry was designed, developed and implemented. Successive exploratory teaching experiments brought to light crucial issues on students' conceptual evolution, which were gradually embedded in the specially developed worksheets leading to an intervention adapted to students' conceptions and learning difficulties. Students' conceptions were brought to light through a complex and manifold process of written predictions, teacher-student discussions and discussions over students' predictions. It seems that during discussions, students realised their alternative ideas and changed them to a considerable extent interacting with the visual experiments under teacher guidance. The discussions between the teacher and the students showed that students recognized and took into account the three factors in order to answer about the amount of heat required when a body was heated. Also, post-test data point out that after intervention students made considerable progress in understanding the factors of the relation of calorimetry.

Although the study has an exploratory character and several features of the present SVL and teaching learning interactions may have affected students, we consider it important to discuss certain features of the SVL that we envisage had influenced students' conceptual evolution. Squires & Preece (1999) discuss that the credibility of a simulation environment can be determined by features such as the investigation and feedback functions, the multiple representations as well as the opportunities offered to students to handle and apply their ideas and solutions to problems. More recently Fourlari et al. (2004), after reviewing several studies, argued that there are a number of features of simulation environments that may promote and contribute, in several perspectives, to the credibility of software from the students' point of view. The features of a simulation environment are classified in three categories: a) The operational features, b) the representations features and, c) the features related to learning. We consider that several features of the SVL involved in the present study seem to be in accordance with the classification concerning the credibility of the SVL and had a meaningful impact to the learning results. The "pausing and restarting", the "time speedup", the parameterisation functions and the sensory and operating plausibility could be classified in the operational features category. The "real time graphing" and the multiple representations features are classified in the representations category. The contribution of the features of the SVL to the intervention, emerging from the teacher's observation during intervention and video analysis of the interventions, is discussed below.

- **Pausing and restarting the experiment evolution**

The SVL enabled students to "freeze" the running of experiments at the crucial moments where one of the two beakers of liquid has reached the final temperature while the other did not yet. During such a pause students had time to think, talk about and write the first results on their worksheet. Students' expressions such as: "*Here! The beaker of the olive oil acquired the final temperature first*" or "*I was wrong…the beaker of the 100gr water came first…*" point out the considerable effect that "freezing" of time offered for making sense of experimental activity. After the elaboration of the data, students continue the experiment from the point that it was paused. It is worth emphasising on this feature of SVL vs. MBL experiments; in a typical MBL experiment, time evolution cannot be interrupted and continued. Another feature of SVL worth noting is the visual simplicity of the simulated experiments. Though very realistic in appearance, beakers in SVL can easily be set as non-radiating or non-interacting thermally. The teacher can pre-set the beaker's properties and fine tune the thermal interactions with the surroundings at a desired level, without increasing the visual complexity of the experimental set up. Much more complex devices would be required in a real laboratory to avoid thermal losses.

- **Parameterization – Time speedup**

SVL facilitates parameterization and this helped instructors to design a holistic approach to the relation of calorimetry. Students assembled the experimental set up by using different quantities, kind of liquids and initial temperatures. Apart from parameterization, time speedup in SVL was another feature, which has made it possible that all three factors in the relation of calorimetry to be studied in two didactic hour’s time, resulting in a feasible holistic approach. Moreover, the fact that students did not have to wait for a long time for the experiments to run, meant that they were kept focused on the study of the three factors of the relation of calorimetry.

- **Sensory and operating plausibility**

One of the features of SVL that helped students comprehend the phenomenon was the plausibility of the operations. Students, as observed, found it easy to work on it. The experimental setup was similar to that of a real laboratory something that helped students get easily acquainted to it.

- **Real time graph - Multiple representations**

In thermal phenomena, such as the change of state of bodies or their expansion during heating, the time evolution of the phenomena relates to visible effects. In the present intervention where the factors of the relation of calorimetry are studied through heating, the time evolution of the experiment has no visible effects except from the movement of the mercury in the thermometer. The real time graph was a significant element of the present intervention not only because it connected the experiment with the theory (Bisdikian & Psillos, 2002) but also because it provided students with a sense of time evolution of the experiment. Analysis of the videos points out that during heating the students constantly observed the real time graph, something that helped them visualize the evolution of the phenomenon.

Students saw the temperature increase of the heated body not only from the real time graph but also from the digital and the analog indication of the thermometer (figure 2). Multiple representations helped students to better visualize temperature and its changes as well as the connection between experiment and theory as has been suggested widely in the literature.

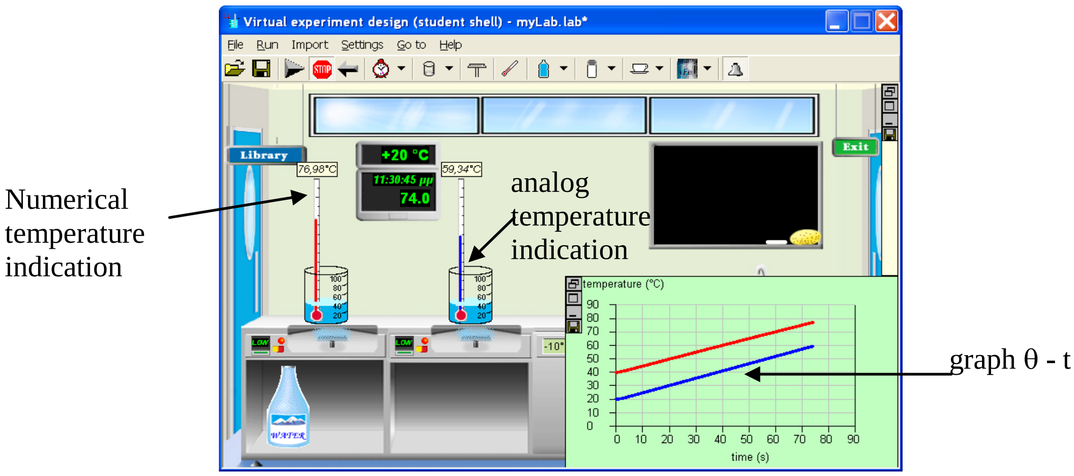

Figure 2. Multiple temperature representations

In addition to the above, the use of SVL allowed the calculation of ***Q*** by the product of the known heat rate with the heating time. In this way, students were helped to develop their understanding of distinction between heating rate from the amount of heat absorbed, as the discussions showed. Also, one unexpected by the designers feature of the SVL is that it is harmless as students mentioned at the end of the interventions that they were not afraid of experimenting because they knew that in the SVL nothing could be broken and there was no chance of being burned from the Bunsen burners. Students’ expressions such as: «*I like experimenting in the Simulated Laboratory because there is no chance of having a boom!!!.....yes!! we were not afraid of burning ourselves*» confirm how important it is for students to execute experiments without the fear of a laboratory accident.

In concluding this paper, we consider that the present study suggests that the use of the present SVL, as a dynamic system, is potentially very fruitful in science teaching, since, as this exploratory study suggests, several of its features have helped both the development and implementation of a holistic and dynamic approach to the study of calorimetry.

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