THERMAL SENSORS INTERFACED WITH COMPUTER AS EXTENSION OF SENSES IN KINDERGARTEN AND PRIMARY SCHOOL

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Abstract
New technologies offer new learning opportunities for teaching science also in primary. Simple experimental situations based on on-line sensors are proposed for interactive activities as a powerful extension of senses. In particular they can allow a phenomenological exploration of thermal processes based on a thermodynamic approach. The exploration of thermal properties by tactile sensation is widened by the use of on-line sensors. In the proposed didactical approach, pupils correlate the processes they realize with the real time graphs they observe, activating imaginative reduction of the concepts under study.

1. Introduction
New information communication technologies (ICT) offer new learning opportunities for teaching science also in primary school (Varisco 1995, Russell et al 2004). Simple apparatuses, based on on-line sensors, are proposed for interactive explorations in formal and informal learning contexts. In the field of thermal phenomena, not only on-line sensors provide a powerful extension of senses but also allow a change from a thermostatic approach to a thermodynamic one (Sciarretta et al. 1990; Vicentini 1996; Bosio et al.1996; Michelini, Stefanel 2004; Adawi, Linder 2005).
Empirical researches carried out with pupils in kindergarten and primary school have shown that these strategies activate important formalization processes, creating a bridge between phenomena and formal representation of their descriptive variables: this approach helps the organization of knowledge on abstract concepts (as thermal equilibrium), the identification of properties characterizing the observed system (Benciolini et al., 2002; Stefanel et al. 2002; Guidoni 2004).
An educational path was developed for learning/teaching thermal processes in primary school, using thermal on-line sensors as extension of senses (Bosio et al 1996; Michelini 2006; Michelini, Stefanel 2004). In this work, it is presented our thermal sensor system (TERMOCRONO), which peculiar familiar interface was studied for activities in primary school and kindergarten (Gervasio, Michelini 2006). It is presented the rational of our path on thermal phenomena focused on the bridge between sensation and temperature measurements by means of real time lab (RTL), with attention to processes. Examples of experimental activities carried out with primary pupils are given. Finally, we discuss of pupils learning stressing on the role of on-line system and RTL.

2. The on-line sensors system: Termocrono
Termocrono is a simple data acquisition system for measurement of four temperatures. It is the last version realized via USB computer interface of a previous developed system: Termografo (Mazzega, Michelini 1996). It is characterized by a user friendly software interface, designed to be usable also by children. The system start the measurement activating a “start bottom”. After a simple selection of which sensors are visualized, the measure appears in a real time plot, dynamic also with respect to the change of scale performed by user during the measure session (fig. 1).

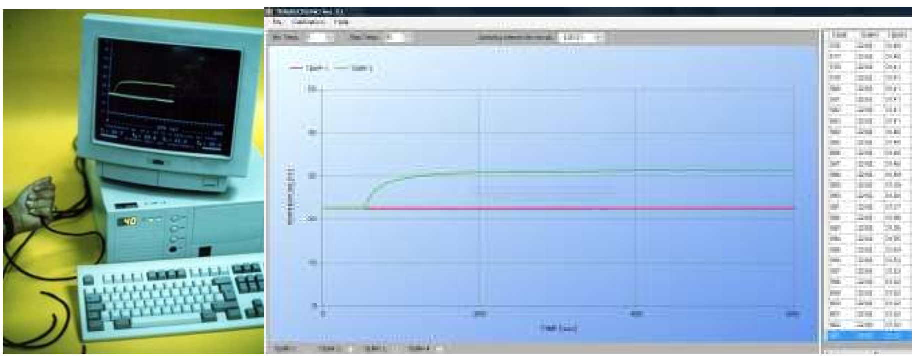

Figure 1: Real time graph and table of temperature values measured with TERMOCRONO: three sensors are put on a table, and the fourth sensor is taken and hold by hand

The temperature measurements range from -10 °C to +120 °C, with 0.1 °C sensibility and 0.3 °C precision. The frequency of temperature sampling is chosen at the beginning of each session by setting the time between two measurements from 1 s to 24 h. Data storage is provided in two formats: internal .xml format and ready to be exported in electronic work sheet in .xls format.

3. The rational of the proposal on thermal processes

The approach to the study of thermal phenomena in primary school focuses on thermal processes (Sciarretta et al. 1990; Vicentini 1996; Adawi, Linder 2005), thanks to use of temperature on-line sensors and the real time graph (Mazzega, Michelini 1996; Bosio et al. 1996; Michelini, Stefanel 2004). Thermal sensation rules our knowledge of everyday life thermal phenomena. Therefore, it is important identify the kind of information given by thermal sensation, distinguish it from the information related to temperature measurement. Common situations of systems interaction are explored through thermal sensation first and temperature sensors after. The equilibrium state with constant temperature in time define temperature concept. The thermal states of the human explorer and the explored system are identified by means of temperature measurements in time. The role in thermal interactions of system properties as mass and volume and the properties associated to matter as the specific heat and the thermal conductivity is recognized and distinguished. The real time graph observed during the experiment activate the link between actions made, processes produced, representation of the evolution of the kinematical variables describing (temperature). The phase transitions, the heating by friction and in chemical phenomena, the light absorption set the problem of the nature of heat and focus the attention on internal energy variation.
Sensors as extensions of senses in the exploration of thermal phenomena are here proposed for the identification and distinction of the sensation processes in exploration of thermal conditions of the different systems. In the next section the 6 steps aim to this objective are discussed.

4. Phenomena exploration by thermal sensation and using on-line sensors

Step 1. Pupils are invited to touch objects standing on a table, made by different materials, having different form, extension, weight (fig.2A). They order the objects, according to the thermal sensation felt. The sequences produced by each pupils are compared, recognizing, from one side, the objectivity of thermal sensation and posing, from the other side, the question to distinguish and share the meaning of “to feel hot” and “to be hot”.

Figure 2: Exploration by thermal sensation felt touching objects put on the table, having: A) different form, dimensions and made by different materials; B) equal form and dimension and made of different materials; C) same form and made by the same material, having different diameters.

Step 2. Discussing on “how it is possible establish how hot is a systems?” pupils answer that have two ways: by means of thermal sensation; by means of a thermometer.
Steps 3. On-line sensors, are proposed in this phase as particular type of thermometers. Pupils take and hold in their hands a sensor. The real time graph observed on the screen (fig.1) activates immediately the link between actions (taking the sensor in the hand) and representation of temperature of the sensor (the rapid change in the represented temperature). The temperature, constant in time starting from a particular time instant, maintaining the sensor in the hand, define the equilibrium thermal state corresponding to the measured temperature of the hand and not only of the sensors itself. To reinforce and share this conclusion an exploration is made putting the sensors in contact with other thermostatic systems, as masses of water at different temperatures.
Step 4. Using a thermal sensor as an extension of senses, pupils explore the systems analyzed before using finger (fig.3). The measured temperature is the same for all the systems in contrast with sensation. It allow the recognition of the different and differently rich information related to: temperature, that give us information to the thermal condition of the system and is determined by

the environment in which the system is putted (the table); thermal sensation, that give us information on the temperature change process and is determined by the properties of the system.

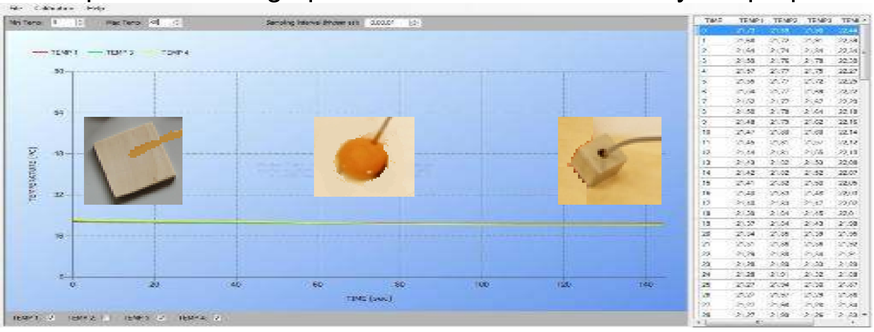

Figure 3: The temperature of the objects putted on the table (showed in figure 3)

Step 5. To recognize the role in thermal sensation of the properties of material of which the object are made and the systems properties (the mass, the form) and distinguish them from state properties (thermal state as thermal condition) the following analysis was proposed first using a finger then a sensor. Pupils explore: equal objects made by different materials (fig.2B), objects of the same forms and made by the same material, but having different masses (fig.2C), objects of different forms, made by the same materials and of the same weight, equal objects (equal cubes made by alluminium) put in different environments (the freezer, the heater, the table).

Step 6. To identify that the thermal sensation is associated to a process, the pupils are involved in the analysis of the Locke's experiment (1690/1959): using a finger, using the sensors (fig. 6).

Figure 4: The Locke's experiment using the fingers and temperature sensors.

Three thermoses are filled of warm water, lukewarm water, and cold water. A finger and a sensor have dipped in the warm/cold water and then in the lukewarm water. The thermal sensation felt are compared with the behavior of the sensors temperature graphs, to recognize that the phase in which temperature of each sensor changes passing from warm/cold environment to the lukewarm environment corresponds to the different felt thermal sensations.

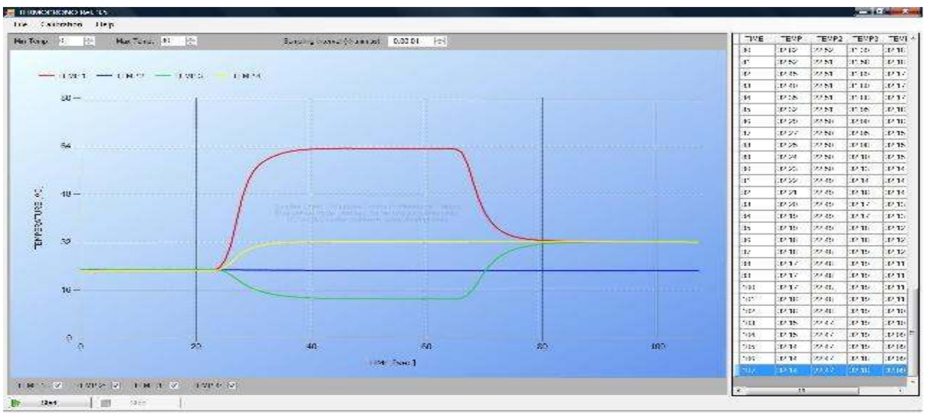

Figure 5: The real time graph for the Locke's experiment.

5. What students learn from on-line sensors exploration

Using the presented educational path, several research experimentations with pupils are carried out from 2000 in formal (in school) and informal (CLOE lab) contexts, as reported in table 1. Here we discuss some general results for the experimentation in Kindergarten and in Primary, referring to the quoted bibliography for more details.

Table 1: Experimentations in schools and in CLOE Labs (I: Institution; C: Class; S: Students)

Experimentations	Kindergarten			Primary			Middle/Low Sec.School		
Contexts	*I*	*C*	*K-S*	*I*	*C*	*P- S*	*I*	*C*	*M-S*
Formal-In schools	5	6	86	7	24	206	4	14	201
Informal-CLOE Labs	5	8	84	8	23	275	5	6	60

The experimentations in the schools are carried out with action research modalities and learning outcomes step by step and they were analyzed with empirical research methods. Data collected are: pre/post test, worksheets for students designed according to the inquiring method (McDermott 2001; Abd-El-Khalick et al. 2004) following a PEC strategy (Lawson 2008) rogersian interviews and standard monitoring tools (Aiello et al.1997). A wide discussed documentation of the experimentations in schools is available also on web (Michelini 2002).

The following main results emerge from the experimentations carried out in kindergarten with the 86 students of the K-S group. In step 1 of exploration of thermal sensation with finger, the pupils: RS1) the object classification performed by pupils refers to some property that must be individuated (80%); RS2) use a representation as much formalized as more abstract are the icons used for the order (objects itself (20%); photos of them (20%); pictures (50%); geometrical figures (i.e. colored squares, circles) with different dimension associated to the sensation felt touching each of them (10%); RS3) recognize that materials and masses of the touched objects have a relevant role in the sensation felt (85%); RS4) recognize the objectivity of thermal sensation (70%) (Benciolini et al 2002; Michelini, Odorico 2004; Binda et al. 2005; Michelini 2006). Using sensors and RTL to explore the own hand's thermal condition and other systems at constant temperature (step 3), they: RS5) recognize the instant when the external condition of the sensors start to change (95%); RS6) associate temperature of the measured system to the part of the graph were the temperature do-not change anymore (more frequently mimicking flatness behavior with hand) (71%); RS7) relate the produced process and the observed graph (81%), RS8) identifying also the correct way of temperature change (40%) (Michelini, Odorico 2004; Binda et al. 2005; Michelini 2006). When the students are request to explore the temperature of the objects putted on the table and previously touched (steps 4-5), they: RS9) say that all the systems have the same temperature (78%) and RS10) this temperature is the same of the table on which they are set (58%); RS11) the different information related to thermal sensations and temperature measurements (61%)

About the results with the 206 students of the P-S group, the main differences with respect to the previous results are: the significantly different percentages of RS6, RS8-RS11 results, bigger as one can aspect for RS6 (92%), RS8 (77%), RS10 (74%), RS11 (85%), lower for RS9 (70%), these pupils emphasized the differences of few tenths of Celsius degrees measured touching the different objects; a greater attitude in using graphs as iconographic/formal representation of the analyzed process (82%) (Michelini 2002, 2006).

For what concern the experimentations in informal context, the methodology of CLOE labs was mainly adopted (Stefanel et al. 2002). Children work in group and are personally involved and stimulated to discuss everyday life scenarios and to face hands-on/minds-on experiments realized with simple objects and on-line sensors. Data are collected by transcription of audiorecorded students discussions in group, the open worksheets filled by each pupil during the CLOE lab and in particular by the open sheets where students sketch the prevision graphs, the observed graphs, write in free form what are the main (explicit) aspect learned during the two hours of the lab.

The results reinforce the previous presented ones (Bosatta at al. 1997, Bosio et al. 1999; Stefanel et al. 2002; Bozzo et al. 2009) evidencing in particular the following.

The real time graphs have a great role in linking observed phenomena with formal representation of time evolution of the temperature and generate concepts and the basic ideas for physics quantities identification. The graph, especially in kindergarten, constitutes an iconographic representation of the processes activated during the experiment as evidenced in the examples reported in figure 6, related to a samples of 31 kindergarten students 4 years aged involved in a

CLOE lab in November 2009 in Crema. The two graphs were produced by pupils at the end of the step 3 of the described path. They represent the observed evolution in time of the temperature of a sensor initially standing in cold water, then took in hand, then diped in hot water, finally put on the table or left into the water. The two reported graphs represent respectively 48% and 26% of the sample. The remaining drawings (26%) are equally divided in graphs reproducing only some observed aspect (a state, a process) and pictures reproducing the hand or the water drops. In the case of fig. 6 Andrea and Nicholas sketched the main elements of the observed graphs: the constant value of the temperatures of the measured systems and the process of heating. Andrea represents the correct concavities too, Nicholas tends to represent the process as linear. The two children correlate the graph plateaus to the systems with which the sensor is in equilibrium, and they used shared icons to represent this fact. They recognize that this association is possible only when the equilibrium is reached and not when the temperature of the sensor changes. The scales on the axes are not reported because the attention is focused on the general behavior of the temperatures.

Figure 6: Graphs made by 5 years hold pupils and reproducing the temperature evolution graph of a sensor put: in cold water ( ), in the hand ( ), in hot water ( ), on the table ( ).

In the case of the P-S group students 68% of the sample explicitly distinguish the phases of thermal equilibrium of the sensor, with the table (initial) and with the hand final), and process phase occurring between them. The use of sensors as extension of senses promote the distinction between thermal sensation, that is connected to a process, and temperature, that is associated to a state (70%). In figure 8 the graphs, sketched at the end of the step 6 (Locke experiment), are reported. The sample is composed of 50 pupils 10-11 years old.

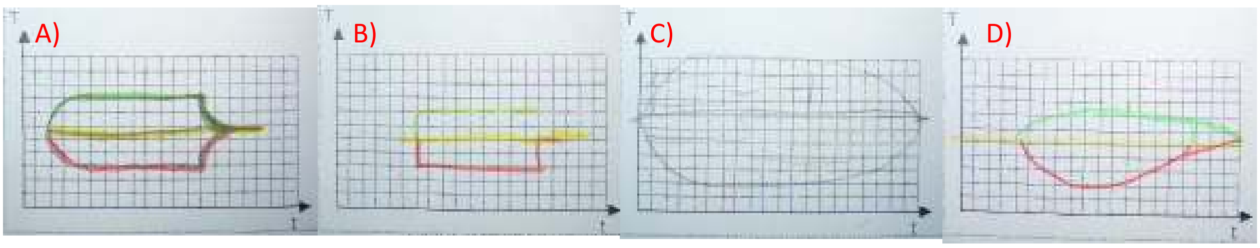

Figure 8: Graphs made by 10 years hold pupils reproducing the graph of the evolution in time of three sensors in the Locke's experiment.

The reported graphs represent respectively four categories: A) The representation of the evolution in time of the temperature of the three sensors are reproduce with great detail and in particular are recognized the transient phases from the warm/cold water to the lukewarm water (28%); B) The equilibrium states are well represented and the temperature changes are represented linearly (20%); C) The phases in which temperature changes are emphasized, while the equilibrium phases are reduced to a point (12%); D) The graph reproduce some aspects of the observed graphs, prevalently as in a pictorial representation of the graph (30%). In the case A) and B), a connection between how the temperature changes and the thermal sensation is felt emerges in the description of student: "The red sensor is in the cold water, the green sensor is in the warm water.." (38%); "The colder is tha lower temperature, the warmer is the higher temperature…" (12%). In the case C) and D) only the transient phase is stressed ("The cold grow up, the warm fall down and in the center the lukewarm" (36%) or only that: "Each sensor have a different temperature" (6%).

6. Conclusions

Computer on-line sensors for 4 point measurements of temperature employed as senses extension is organized in inquiry learning conceptual path experimentated in kindergarten and in primary school. The pupils are involved in the analysis of common situations first exploring processes using the finger as a sensor, then extending the range of the sensorial exploration using sensors interfaced with computer. The learning environment and the strategy used link common sense and the scientific vision of phenomena. Also the sensors on-line are proposed and used as toys, contributing to this goal, in particular in informal learning context. The data here reported evidence that children also 4-5 years old recognize iconic elements of the graphs, associating it to the experienced processes. In the case of primary these elements push the pupils to explicit formal thinking. Sensors become extension of senses because by means of them pupils explore phenomena, recognizing the role of thermal properties; they identify the different information associated to transient phases and to the equilibrium ones. The real time graph bridges pupils from the sensorial experience to a formalized conceptualization of processes.

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