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Teaching materials' properties to K-12 students using a sensor board

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ABSTRACT

In this work we present two teaching modules, based on the combination of Scratchboard and Scratch, to be used for the study of thermal properties of materials, such as thermal conductivity and heat capacity. These properties are very important for the understanding of many applications. In the design of the modules we have taken into account two scenarios, one for elementary and secondary school students and one for high school students. This determines not only the type of measurement and the analysis of the data, but also the Scratch interface. The main emphasis for the lower grades is placed on the introduction of the concepts and a demonstration of the differences of the properties of different materials, while for the upper grades for making accurate measurements through inquiry based projects. Both modules have been implemented in a high school laboratory, providing reliable measurements and engaging the students in a higher level than usually.

INTRODUCTION

The progress of ICT (Information Communication Technologies) provides tools for improving the quality and the ease of access to education and training. For science teaching, data acquisition systems are a powerful tool for real-time measurements and the presentation of various physical quantities in school science laboratories. These systems are generally quite expensive and sophisticated for the average students' use. In this work an alternative system is proposed: the combination of Scratchboard and Scratch. Both of them have been developed in the MIT Media Labs; Scratch Board is a sensor board coming with several embedded sensors. On the other hand, Scratch is a new freeware multilingual programming environment that can be easily used by pupils to create their own animated stories, video games and interactive art and share their creations with each other across the Internet [1-4]. Both Scratch and Scratchboard have been developed to be used in a very wide field of activities. This system is not specifically addressed to science lessons' activities; there are integrated data acquisition systems for such a use available. One nice feature of Scratchboard is that it has several sensors embedded and comes to a very low price, less than fifty Euros. In addition, it communicates with Scratch, which is a LOGO-based education oriented software. This gives rise to the research question: can this system be used to study thermal properties of materials such as thermal conductivity and heat capacity in school laboratories? Seeking an answer to this question, we designed two teaching modules and we are also in the process of preparing a new set of activities on subjects like optical and electrical properties.

Theory

The steady state conduction is the form of conduction which happens when the temperature difference is constant, so that after an equilibration time, the spatial distribution of temperatures in an object does not change (for example, a bar may be cold at one end and hot at the other, but the temperature gradient along the bar does not change with time). In short, temperature at a section remains constant and it varies linearly along the direction of heat transfer [5]. In the steady state conduction, the amount of heat entering a section is equal to the amount of heat coming out. There also exist situations where the temperature drop or raise occurs more drastically and the interest is in analyzing the spatial change of temperature in the object over time. This mode of heat conduction can be referred to as *unsteady mode of conduction* or *transient conduction* [6]. Analysis of these systems is more complex and (except for simple shapes) calls for the application of approximation theories and/or numerical analysis with the use of a computer [7]. The mathematical description of transient heat conduction yields a second-order parabolic partial-differential equation [8]:

$$\frac{\partial U}{\partial t} = \kappa \nabla^2 U \tag{1}$$

where κ is the thermal diffusivity and $U(x,t)$ is the temperature.

When applied to regular geometries such as infinite cylinders, spheres, and planar walls of small thickness, the equation is simplified to one having a single spatial dimension. With specification of an initial condition and two boundary conditions, the equation can be solved using separation of variables -- leading to an analytical expression for temperature distribution in the form of an infinite series. The time-honored Heisler charts were generated a half-century ago using a one-term approximation to the series, and have been used widely ever since for 1-D, transient-conduction applications [9]. The general solution of equation (1) is [8]:

$$\mathrm{U}(\mathrm{x}, \mathrm{t}) = e^{-\kappa t/\lambda^2} \left[D\cos\left(\frac{x}{\lambda}\right) + E\sin\left(\frac{x}{\lambda}\right) \right] \tag{2}$$

where

$$\frac{1}{\lambda^2} = -\frac{1}{\kappa T}\frac{dT}{dt} \tag{3}$$

EXPERIMENT

Scratchboard is connected to a computer through a serial-to-USB cable that comes together with the board. The communication protocol is the RS-232 and the transfer baud rate is 38.4k. The connection between Scratch and Scratchboard is realized using sensing blocks. Sensor value blocks give readings ranging from 0 to 100 or ranging from 0 to 1023 if the user prefers to read raw 10-bit data [10]. These values can be used to control graphic effects or can be stored in a log file.

In a stanchion we placed a steel bar with 30 cm length and 5mm diameter (Figure 1a).

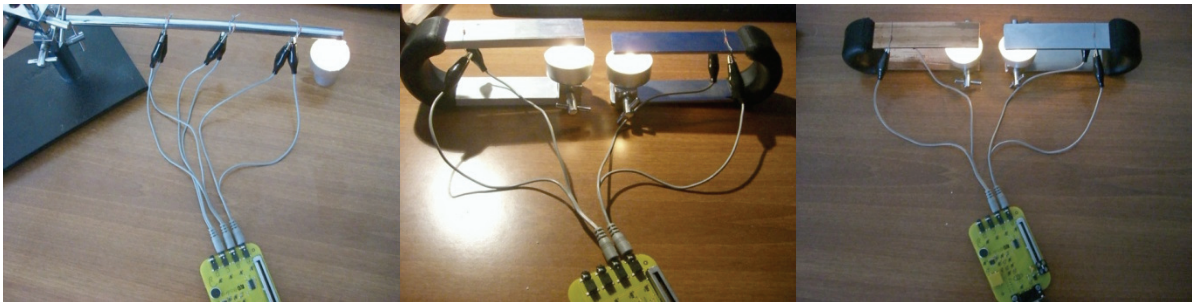

Figure 1. **a.** The steel bar is heated and three thermistors record its temperature at three different points. **b.** Two horseshoe aluminum bars with a thickness of 3mm and 8mm respectively are heated and two thermistors record the temperature of each one at some point. **c**. Two horseshoe bars (a copper one and an aluminum) with a thickness of 3mm are heated and two thermistors record the temperature of each one at some point.

Alternatively we used horseshoe bars of the same material (aluminum) and different thickness (3mm – 8mm) (Figure 2b) or the same thickness (3mm) and different material (copper – aluminum) (Figure 2c). In all cases one of the ends of the bar was placed above a candle flame. The rate of combustion should remain constant for all the experiments in order to provide heat at a constant rate. Along the bars thermistors were placed, connected with Scratchboard through alligator clips. As the bars were heated, the resistance of the thermistors was raised and their values were recorded. As these values are in arbitrary units; we used a digital thermometer for calibration. According to the level of the students we addressed the Scratch's interface differently. For elementary level students a bar was shown, with its color changing from point to point according to the chance of the temperature. For secondary level students graphs were provided that presented the change of temperature versus time (Figure 2).

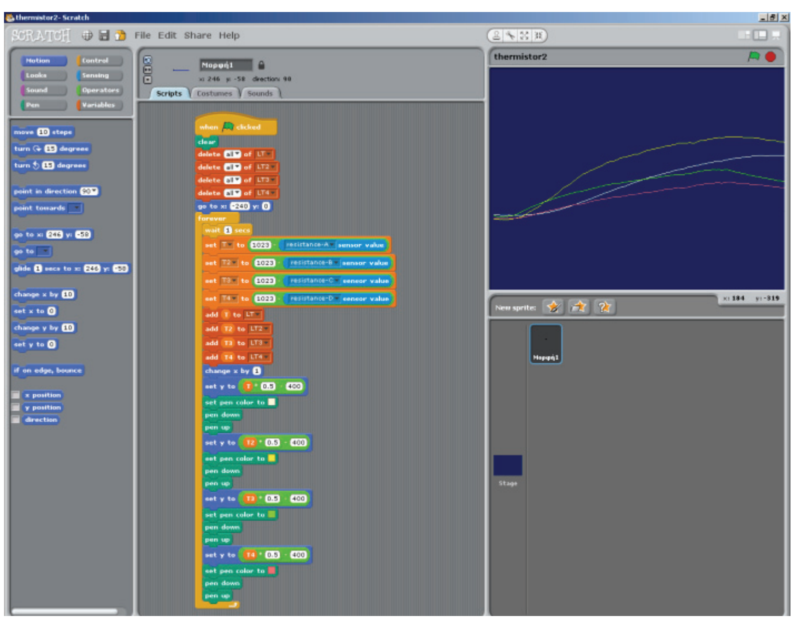

Figure 2. A Scratch's screenshot.

DISCUSSION

Students realize the setting presented in Fig. 1a and start the measurements. Data collected for about 40 minutes are presented in Fig. 3.

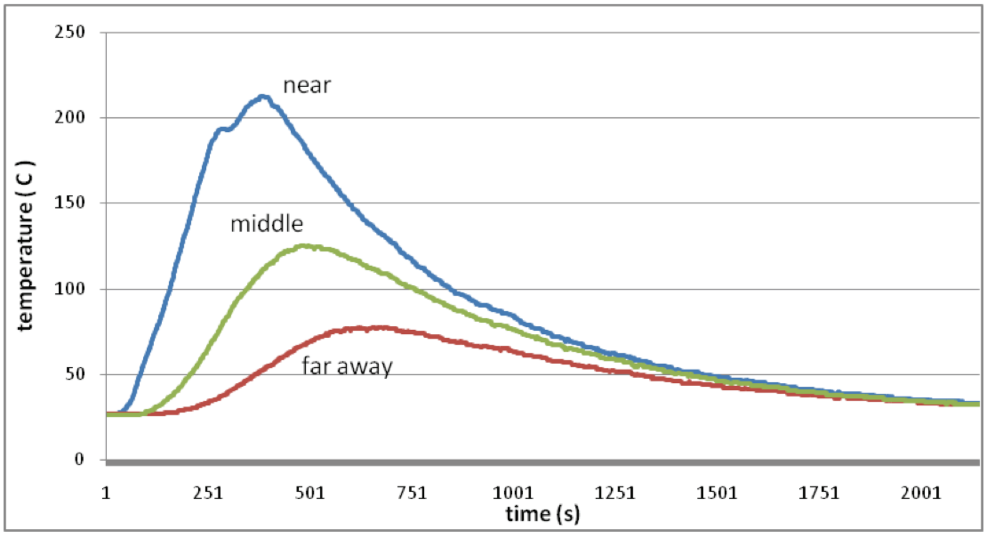

Figure 3. Temperature vs time at three points along a steel bar.

The heating of the bar's end is terminated at the moment that the temperature of the nearest sensor reaches its maximum (blue line). It is obvious in Fig. 3 that the temperature acquired at various points of the bar depends on their distance from the heating source. The closer to the source they are, the higher their temperature. It is also obvious that, for bar points far from the heat source, the temperature continues to increase, even after the interruption of heating (energy offer), due to the heat conduction from the hotter end to the cooler end of the bar. Finally, during the cooling process, curves are compatible to Newton's law of cooling. Students then realize the setting seen in Fig. 1b. Data collected for 40 minutes are presented in Fig. 4.

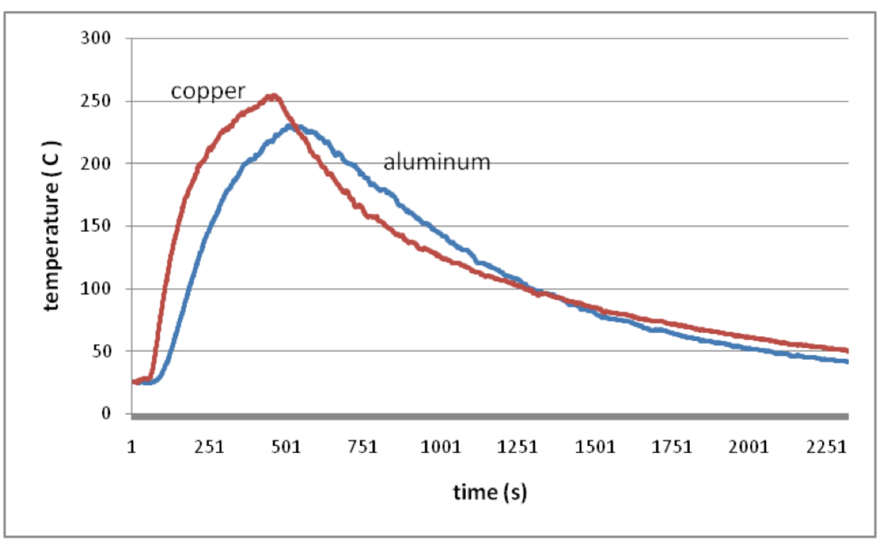

Figure 4. Temperature vs time at two points of a copper bar and an aluminum bar.

From Fig. 4, we can observe that the copper bar reaches faster higher temperatures than the aluminum bar, because of its higher thermal conductivity and lower heat capacity. Finally, students constructed the setting presented in Fig. 1c and started the measurements. Data collected for about 15 minutes are presented in Fig. 5.

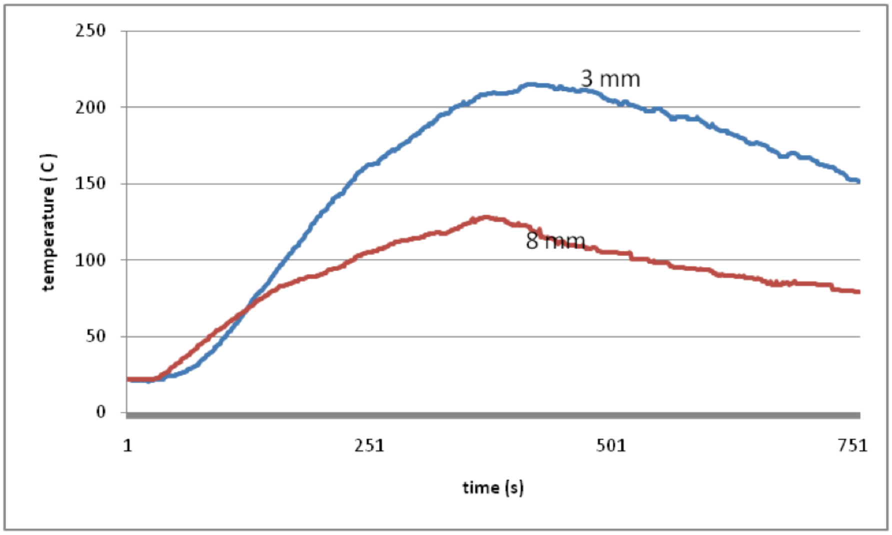

Figure 5. Temperature vs time at one points of two aluminum bars with different thickness.

Two phenomena can be distinguished in Fig. 5: a) because the thicker bar has a larger thermal conductivity, its temperatures increases more rapidly (at least in the beginning), and b) due to its bigger mass, the thicker bar's heat capacity is larger than the thinner bar's, resulting in a higher final temperature for the thinner bar. The graphic representations that came out are in very good agreement with results of simulations [11], [12], and they provide the chance to discuss the laws about the phenomena through inquiry based hands on activities.

It is quite obvious that this setup can provide an accurate measurement of the physical quantities involved after the thermistors' calibration. In addition the low cost apparatus offers the chance to all students in a science class to study a law of Physics by participating in such a hands-on activity. At least in Greek schools, students usually just watch their teacher performing a high accuracy measurement experiment, using an expensive data acquisition system.

CONCLUSIONS

Data acquisition systems provide a powerful tool for measuring and presenting online various physical quantities in school science laboratories. As these systems are in general quite expensive and sophisticated, the use of Scratchboard and Scratch could provide an alternative solution for most schools' laboratories. According to our experience, the appropriate use of such a system amplifies the possibility for students to be engaged in the learning process through programming, inquiry based and hands-on activities. Technically speaking, the sensor board can measure several physical quantities simultaneously and the powerful user-friendly software makes the presentation of the data as well as their processing easy. There is no doubt that the proposed system cannot totally replace the specialized data acquisition systems in upper secondary schools, where the students do have to make precise measurements. But it could be used in a very promising way in lower secondary and in primary education, where sophisticated data acquisition systems usually do not exist. This way would alter students' interest about science and laboratory activities.

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