Using models to illuminate experimental data

Laurence Rogers
School of Education, University of Leicester, England

This workshop presents a new generation of data-logging software which facilitates enlightening comparisons between data from mathematical models and data gathered in real experiments. By integrating the functions of data-logging, modelling and graphical analysis, the software environment allows pupils to explore scientific ideas which can be described mathematically. Participants will be invited to try out and evaluate sample activities designed to encourage thinking which employs previously learned scientific principles, or to make predictions which may be tested by experiment.

Introduction

Computer software can provide valuable tools for exploring data collected from laboratory experiments (Rogers, 1996). The special value of such tools resides in the use of graphics to visualise trends and changes in data, and the variety of rapid calculating facilities, useful for analysing the data and for deriving secondary data. The instant access to calculations and the interactive possibilities for their use are key attributes of the computer-based method of handling data. The graph is an important method for presenting data and each graph shape has unique properties (Rogers, 1998). Recognition of these properties can help lead students to a better understanding of the relationships between variables represented by graphs. Further, the graph can be regarded as a 'bridge' between informal descriptions of relationships based on simple observations and more formal descriptions using mathematical formulae (Rogers, 2001). The properties of formulae are revealed by exploring the characteristics of graphs, and an understanding of such properties leads to an appreciation of a relationship between variables. It is now proposed that newly designed software (Logotron, 2009), by offering a common user interface for comparing data-logging and model-generated data, and by presenting models in a graphical iconic environment, greatly assists students in developing an understanding of the mathematical description of phenomena.

Data-logging and graphing

Data-logging (or MBL) implies the use of a computer for physical measurement in laboratory experiments. The technology for data-logging is now a well established, but despite its widespread use and well rehearsed claims (Nakhleh, 1994; Pecori, 1998), there are voices of caution about its effectiveness in promoting scientific understanding (for example, Newton, 1998; Pinto & Aliberas, 1996). Pinto & Aliberas warn that software alone is unable to dispel ambiguities and emphasise the importance of teacher interactions to encourage thoughtful application of the software. Enlightened software design can amplify the agenda of science thinking when the degree of operational skill required is reduced. Essential to any data-logging software program are the graphing facilities, and the best examples provide numerous tools for analysing the graph and deriving relevant useful information from the graph.

Mathematical modelling

Modelling activities attempt to simulate the collection of data through the application of suitably defined formulae. A valuable aspect of modelling is the opportunity to control variables and experiment with relationships in ways which are often very difficult in real experimental situations. In this respect, modelling can expand investigative activity and broaden students' experience of a phenomenon beyond the normal limitations of laboratory work. As with data-logging, the principles of modelling are well established but there seems to be no common agreement about the most suitable software design for modelling activities. The commonest tool in use is the spreadsheet, but although this is a powerful and versatile tool, it has serious limitations for displaying the conceptual thinking implied in formulae and equations. Also, the use of graphing and analysing facilities in spreadsheets tends to demand a high level of operational skill which can impede useful scientific thinking . One solution to this problem is to create purpose designed software for specific tasks. The growth of simulations offering virtual experiments is such a response, but most are still limited by the lack of access to the mathematical model itself allowing it to be changed. Borkowski (1996) has warned that too much trust in virtual experiments can promote a false view of reality and recommends correlation with real data collected through data-logging techniques. An attractive solution is to offer a unified software system featuring both modelling and data-logging facilities (Mulder, 1996) but in many school situations, the available software is so complex, students need additional help (Zelenda, 1996).

The *Insight* approach to modelling

The approach described in the remainder of this paper addresses three main themes:

- a software environment which allows seamless interchange between real experimental data and that generated by models, enabling easy comparison
- a simple user interface for modelling suitable for students aged twelve and upwards
- a graphical iconic environment for modelling which helps to structure pupils' thinking.

The examples are based upon the use of *Insight iLOG Studio* (Logotron, 2009), a newly published software package which integrates data-logging, modelling and graphing facilities.

Example 1: Exploring the properties of a formula

For younger pupils a first step in thinking about models can begin by considering how a simple formula conveniently describes the relationship between two or three variables. As a mathematical device, a formula can be regarded as one which both describes and predicts the behaviour of variables. A particular formula provides an appropriate model if its descriptions and predictions match observed data for the phenomenon under consideration. The formula has characteristic properties which are not dependent on physical phenomena but are determined by mathematical axioms. A useful starter activity in modelling is to study these properties first by using the formula to calculate new data from supplied data.

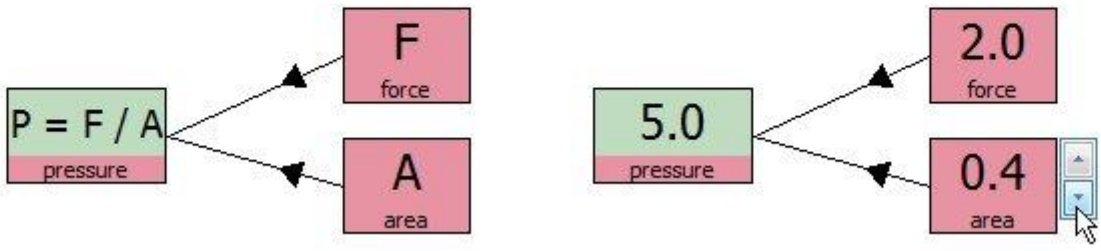

Fig.1a. Model for calculating pressure. Fig.1b. Model in Run mode.

The user interface described here uses the 'input - process - output' flow model and represents this graphically on the screen as a series of connected blocks. (Figure 1a) The calculated variable block (pressure) shows a formula which identifies the variable as the 'output' variable or 'subject' of the formula. In this example the variable blocks for force and area are the inputs for the formula and the arrows indicate this relationship. When model is set to run, the values for force and area may be adjusted and the calculated pressure appears simultaneously (Figure 1b). In this first example the student explores the properties of a simple definition, that of pressure. Students are taught that the concept of pressure arises from the need to describe the effect of a force when applied to a surface area. There is plenty of experimental evidence to support the notion that distributing a force over a large area has the effect of reducing the penetration of the force into the surface. Classic examples of physics teaching featuring sharp knives, snow shoes and large tyres for tractors, exemplify this simple principle. 'Pressure' emerges as a very useful concept for measuring the concentration of a force and hence its penetrating effect. The formula for the definition of pressure, 'P = F / A', can be explored by students using the modelling program simply by entering a variety of 'input' values for 'F' and 'A' and observing the calculated values for 'P'. Such explorations reveal that the formula has just the right properties for describing and predicting the penetrating effect of a force. Students are able to draw the following conclusions:

1. A larger force produces a larger pressure when the area remains constant.
2. A larger area produces a smaller pressure when the force remains constant.
3. If the force and area are each increased in the same ratio, the pressure is the same.

This simple format of activity is no more than a calculating exercise which could be achieved with a calculator or a spreadsheet. However, it is proposed that, in this modelling system, the graphical format on the screen helps to focus students' attention on the variables rather than on the mechanics of the calculation process. Furthermore, after a step-by-step usage, the modelling system permits a rapid sequence of calculations in which one variable is automatically incremented, inserted in the formula and the calculated results simultaneously viewed in the form of a graph (Figure 2). The properties of the graph are readily explored using the analysis tools in the program. Thus the inverse proportion property of the curve becomes evident when students examine the effect on values of pressure as the area is increased in simple multiples. Values are easily compared using cursors which are automatically cross-referenced between the table and graph. The connectivity between the symbolic display, the calculated results in the table and the graph provides a great advance upon the alternative methods with calculators and spreadsheets.

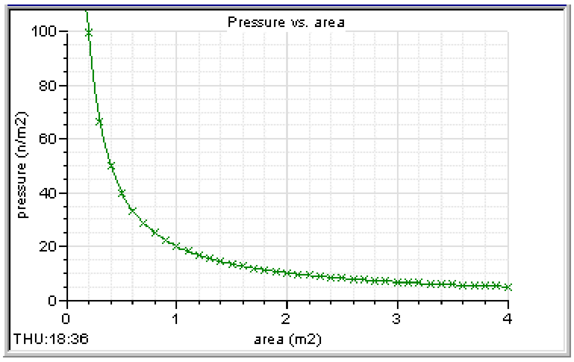

Fig.2. Graph of pressure vs.area.

Example 2: Simulating experimental data

This example describes a modelling activity used to follow up an experiment to study the motion of an object in free fall. A weighted card is dropped from a series of different heights measured by the students and for each height its velocity is recorded as the card passes through a light gate. The program records the series of values for velocity and height and displays them as a table and graph. Students can experiment with the graph analysis tools to study the shape of the graph and deduce the relationship between velocity and height (Figure 3.) The model is then built with the aim of emulating the collected data. The model illustrated here (Figure 4) is based on first principles, relating the

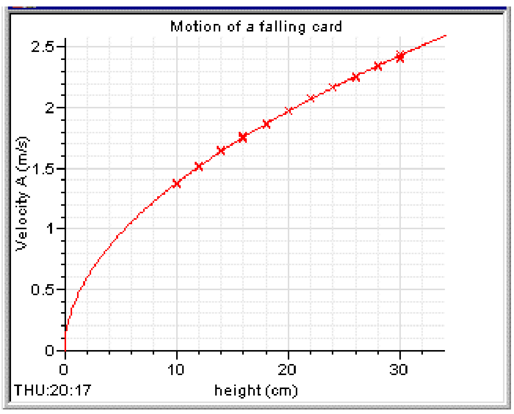

Fig. 3. Graph of velocity vs. height

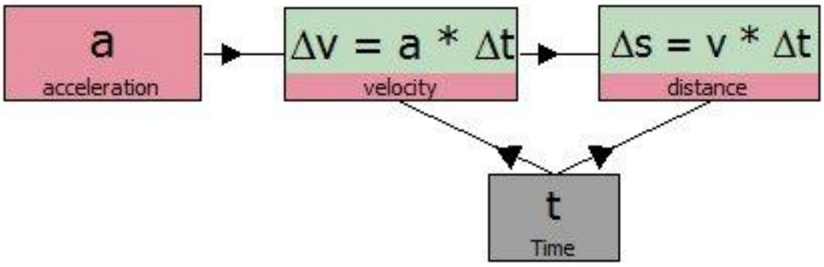

Fig. 4. Model for the motion of a falling object.

distance, velocity and acceleration of the card. The display helps to emphasise the simple dependencies between the variables. The two formulae are merely rearrangements of the definitions of velocity and acceleration. Care must be taken to define increments in distance and velocity rather than current values. In this way the model can accommodate varying rates of change. When the formulae specify increments in this manner, the modelling system performs iterative calculations using the two formulae and automatically calculates the sums of incrementing values for distance and velocity. In this model it is implicit that the value of acceleration remains constant. Students are free to experiment with choosing different values for acceleration and observe how closely calculated data matches the experimental data in terms of the shape of the graph and the actual values. Such explorations can be conducted using the very same analysis tools as those used earlier on the experimental data.

The model is easily adapted to describe other sorts of motion. For example, for a mass-on-spring oscillator, a further formula may be added to calculate the acceleration which will change according to the tension in the spring, and this in turn depends upon the displacement of the mass. The feedback in the model results in a loop of dependencies which are presented visually in the model window. The geometrical arrangement of the blocks can be re-ordered at will to enhance students' appreciation of the relationships. (Figure 5). This graphical feature is a useful aid for structuring students' thinking.

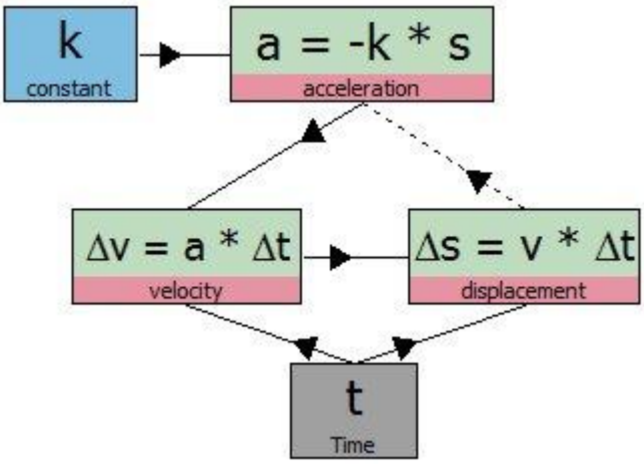

Fig. 5. Model for Simple Harmonic Motion.

Example 3: Extending an investigation

In recent years curriculum programmes in the UK have placed an increased emphasis on an exploratory style of learning in which pupils are encouraged to take responsibility for designing and performing experiments. Typically this involves thinking about variables and setting up 'fair tests' with suitable controls. When real experimental facilities become exhausted, modelling is ideally placed to extend opportunities for investigative work This third example considers an empirical investigation into the effect of volume to surface area ratio on the cooling of a hot body. As with any model, it is necessary to make a number of simplifying assumptions. Student discussion of such assumptions should be regarded as an essential part of the modelling process for it to contribute to the development of scientific thinking. Here the first assumption is that the object under consideration is in the shape of a cube. Thus the size of the object may be described by a single variable, the width of a cube side. Surface area and volume may be calculated as secondary variables, other variables being the temperature of the cube and elapsed time. The model also includes two constants; the temperature of the surroundings and a general constant 'k' encompassing all the physical processes which are likely to contribute to the storage or loss of heat. This approach deliberately avoids analysing these processes into any more detail and allows the main focus of attention to remain on the following assumptions:

1. The rate of heat loss varies in proportion to the surface area of the cube and the temperature difference between the cube and its surroundings.
2. The heat stored in the cube varies in proportion to the volume of the cube.

The model with some sample results is shown in Figure 6. Pupils can investigate the effect of changing the width of the cube, the temperature of the surroundings and the general constant 'k'.

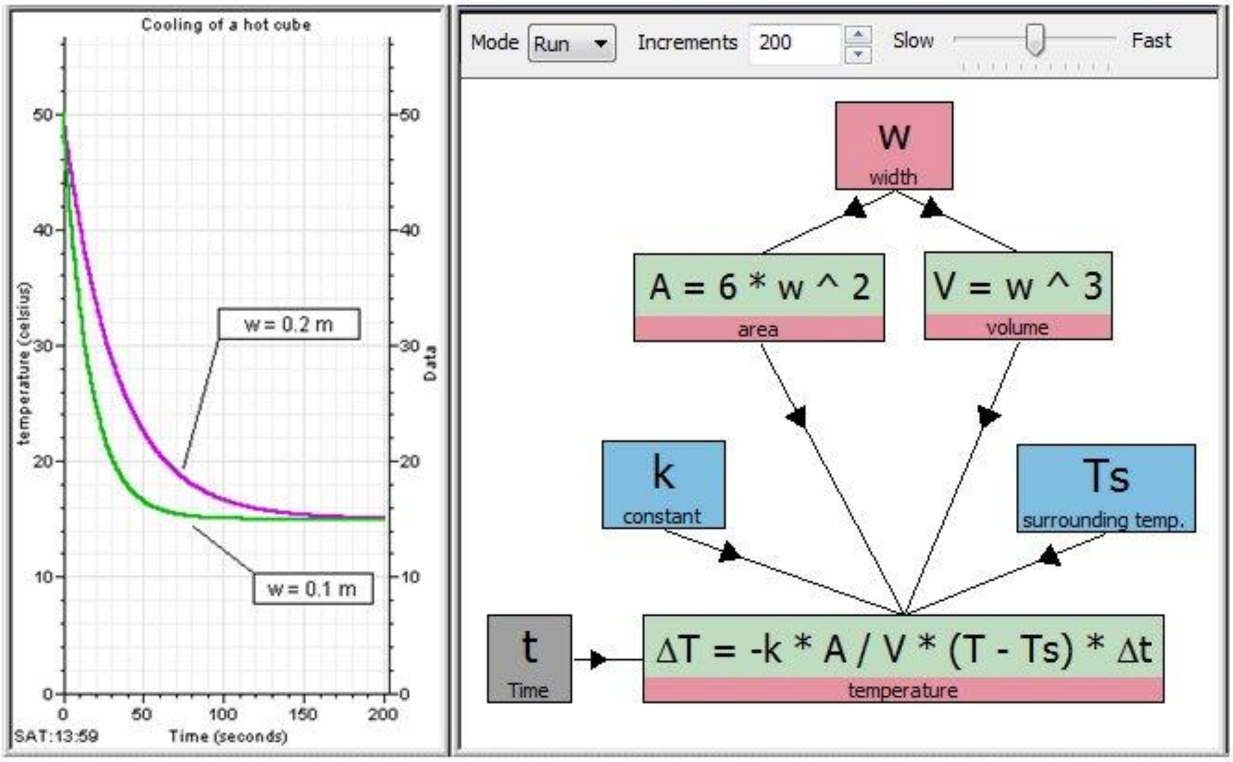

Fig. 6. Model and results for a cooling cube.

Summary and conclusion

It has been argued that modelling compliments data-logging and graphing in helping students explore scientific ideas. The distinctive contributions of these activities are summarised thus:

- Data-logging supports an investigative style of working where the emphasis is upon gathering real data. The automation of the gathering process frees the student to give closer attention to results and their significance.
- Graphing software supports the exploration and analysis of data.

- Modelling supports theoretical engagement with the phenomenon, thinking about relationships between variables, application of principles and making predictions.

For the latter contribution to succeed, the software environment for modelling must help the user focus on the science ideas and develop their skill in thinking through the problem. The visualisation of the variables, constants and formulae and their interconnections in a graphical environment, making the modelling process more explicit and helping to structure thinking, is a contribution towards this aim. This overcomes the weakness of standard spreadsheets and some other modelling software which tend to inhibit conceptual thinking through their complexity or stylised format and syntax.

The approach presented here attempts to give improved access to younger students. In particular, the first example develops the idea that a formula is a conceptual tool for describing a relationship rather than a mere mathematical device for processing data. Each formula possesses valuable information about a relationship; proportionality, inverse proportion, exponential and so on. Also, at any level, the role of discussion in validating models and the questioning of their assumptions should be regarded as an important aspect of modelling activity. These pedagogical considerations are assisted by the unified software system employed here which, by integrating modelling, data-logging and graphing facilities, helps to minimise software operational skills requirement.

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