The Challenge of Developing Innovative Science Teachers with ICT

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Brief description:
To realise the potential learning benefits of activities with ICT tools requires understanding and skill. A recently completed European project has devised training materials to help teachers achieve these.

Abstract
This article begins by reviewing some important software tools which have benefits for science teaching and then describes ways in which the teacher has an important influence on the success of ICT activities in the classroom. Through examples of how such tools may be used to create new activities, we discuss some of the skills and teaching approaches needed to exploit their potential for learning. We then look at a model of teacher development and suggest how the training materials developed by the *ICT for Innovative Science Teachers* Project might be used in future training courses to meet the challenge of a changing pedagogy with ICT.

Key words:
ICT data-logging simulation

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Introduction

The innovative science teacher is always seeking new ways of teaching to improve the quality of learning by pupils. The process frequently involves the use of new educational tools, new activities for pupils and, at its most innovative, adopts or evolves new teaching approaches. Foremost amongst new teaching and learning tools are those offered by ICT, tools which hardly need introduction, but which nevertheless need careful thought about their educational value and discrimination in their use.

ICT is now ubiquitous in everyday life, providing a bewildering array of potentially useful educational software. In order to navigate the diversity, it is helpful to consider Papert's classification of software types, which, although formulated in 1999, is still useful for shaping thinking about pedagogical objectives:

[Insert Table 1]

Ideally the use of these two types of software should complement each other: informational software communicating the authority of established facts, theories and understanding, contrasted with constructional software facilitating experimentation, discovery and the testing of theories. However, in recent years the quantity of software published in the informational category has become so large that it now dwarfs constructional tools. There is a great danger that this imbalance might lead to the neglect of the latter, which may deprive science education of valuable opportunities for innovative teaching and learning. Against this background, the *ICT for Innovative Science Teachers* Project (ICT for IST) has striven to raise science teachers' awareness of the teaching and learning benefits of constructional tools by developing resources for teaching training programmes, in the context of both pre-service and in-service provision.

Software tools for assisting learning

A common characteristic of a constructional tool is that it endows the user with a large measure of autonomy, permitting experimentation but demanding discipline for genuine learning outcomes. Often, such tools possess features which are difficult to replicate with conventional methods. Software simulations are the most popular in this group and to consider the qualities that make simulations potentially useful for learning, an example is shown from the *ICT for IST* Resource Pack.

[Insert Figure 1]

This is a simulation which leads to ideas about terminal velocity. Exerting a force on the pedals causes acceleration. Exploring this, you soon discover that a constant force does not produce a constant acceleration. The velocity increases at first but, as the acceleration diminishes, the velocity reaches a maximum value. Increasing the force on the pedals does produce more acceleration but it is short lived. The physics of this scenario requires consideration of not only the force exerted on the pedals but also the forces of friction which arise due to air resistance and friction in the mechanism of the bicycle. Altering the display to show the model can help pupils understand how the forces and resulting motion are related:

[Insert Figure 2]

The situation is made complex by the fact that the frictional force due to air resistance is not constant but varies with velocity. A great virtue of the model is that it helps to break down sophisticated motion into smaller easily understood steps.

- The acceleration is calculated from the resultant force using Newton's 2nd Law of Motion
- The resultant force is obtained from the vector sum of friction and pedalling force. Since they are opposed this is achieved by subtracting the frictional force from the pedal force.

- The frictional force depends upon the velocity. (directly proportional in streamline flow but proportional to the square of velocity in turbulent flow)
- The velocity changes according to the magnitude of the acceleration.
- The mutual dependence of variables in a feedback loop emerges.

Doing such multiple calculations manually is out of the question, but the computer modelling system performs these calculations without difficulty. So here is an example of a piece of software which apparently provides a novel experience for experimenting.

Affordances of software

Teachers and educational researchers have used various terms for describing features of software which seem to be useful or beneficial:

- Qualities of software (suggesting valuable attributes which may be unique to the software)
- Affordances of software (commonly used in research literature and defined as "The attributes of the setting which provide the potential for action")
- 'Added value' of software (informal terminology suggesting value above what might be expected of conventional methods/tools)

Our research has made several attempts to identify the 'added value' of ICT and this has led us to distinguish between two types of affordance of software:

- **Properties –** self-evident useful attributes of software which require no interpretation; they do not need research evidence for validation
- **Potential learning benefits –** dependent on the actions and skills of a teacher; they are 'potential' because they are not guaranteed – they need the actions of a teacher. (Newton & Rogers, 2001, p.45)

In the *ICT for IST* Project a great deal of attention has been given to identifying such affordances as we believe they are essential components of *knowledge* required by innovative teachers. In the case of simulations the following are proposed:

Properties:

- Eliminates need for expensive apparatus and setting-up time
- Results may be obtained quickly
- Graphical tools are available for analysing data accurately

Potential learning benefits:

- There is greater scope for investigation with a simulation which is not bound by the limitations normally constraining a real experiment
- Visualisation of phenomena through animated images can support motivation and engagement with the concepts involved

The role of the teacher

On their own, software tools cannot guarantee learning outcomes. The success of ICT depends upon many factors which include pedagogical approaches (Webb, 2010) and much research has demonstrated that the role of the teacher in mediating the use of ICT is of crucial importance (Kennewell, 2001; Pedretti, 1999). Thus our project has given a high priority to providing pedagogical advice.

For tools to be successful, *skills* are needed to make their use effective. We identify three types of skill that are necessary:

- **Operational –** technical skills for operating the computer and software
- **Procedural –** Strategic skills for performing activities in a manner which benefits teaching and learning
- **Pedagogical -** Teaching approaches which benefit learning (Newton & Rogers, 2001,

pp.141-144)

The importance of procedural skills is that they are about putting theory into practice – applying scientific knowledge to the use of the ICT tool for the purpose of learning or understanding. *Operational* and *Procedural* skills are required by ALL users, both teachers and pupils, whereas *Pedagogical* skills are the domain of TEACHERS.

To consider these skills in more detail, we present an example of a simple data-logging experiment using a motion sensor. The essence of data-logging in general is the use of sensors for making measurements in real experiments. When connected to the computer they send a stream of data which can be immediately presented on a graph in data-logging software. In this example, a motion sensor detects the position of objects placed in front of it and allows distance time graphs to be plotted simultaneously on the screen. Whilst standing in front of the sensor, any movement made by a pupil is recorded as a distance – time graph.

[Insert Figure 3]

The immediacy of plotting gives pupils a first-hand opportunity to make mental connections between their physical movement and the shape of its symbolic representation in the graph. This is a quality of experience which is unequalled with conventional measuring instruments. The speed of movement, its direction and steadiness are all represented by features of the graph. The shape of the graph tells a story of a pupil's motion as he or she walks backwards or forwards or pauses in between. Once captured, the data may be analysed using software tools; for example, the furthest distance may be measured using a cursor, the gradient indicating speed and direction may be measured at any point on the graph, a new graph of velocity against time may be plotted from calculations performed on the original data.

So here is a powerful measuring tool, but what skills are needed to make it useful in the classroom? Some of these are identified in the teacher's commentary in our project modules:

Operational skills with data-logging

- Connecting sensors and interfaces
- Choosing logging parameters
- Starting and finishing real-time logging
- Retrieving data stored in data-loggers

Employing data-logging in an educationally purposeful way involves these *procedural* skills:

- Exploiting opportunities for novel experiments
- Active observation during real-time logging
- Evaluating measurement quality
- Analysing data using graphs

The data-logging experiment helps to illustrate why the role of the teacher is so important. Pupils need training to acquire the operational skills; although some of such training could be achieved through the use of worksheets or on-screen instructions, pupils still look to the teacher as a role model in practical work. Further, considering the procedural skills identified here, the teacher has a vital role in helping pupils acquire these skills through the design of the tasks and through interactions in the classroom. The teacher is the *architect* of the tasks which aim to deliver learning benefits, but is also the *manager* of the learning process by which pupils acquire the necessary skill with the software.

Professional Development

How do teachers acquire the skills to become effective ‘architects’ and ‘managers’? In general, professional development needs to address three aspects of how teachers perform their role: their beliefs, knowledge and skills (Bell and Gilbert, 1996, 2004). Courses for teachers, whether they be pre-service or in-service, need to be designed with all three factors in mind.

Beliefs – Teachers' beliefs underpin virtually every decision or judgement that they make in their professional role. Fundamentally, what are the teacher's beliefs about how children learn? How does ICT challenge these beliefs? Does the teacher believe that ICT can contribute to improved teaching and learning?

Knowledge – Teachers are assumed to be knowledgeable people, but precisely what knowledge do we expect a teacher to have? Teacher educators usually break this down as follows:

- Subject knowledge
- Pedagogical knowledge
- Pedagogical Content Knowledge (PCK) (Subject-specific pedagogical knowledge: rationale, curriculum, assessment, instructional strategies, pupil understanding)

To accommodate ICT, to this knowledge must be added, "knowledge of how the wide range of technologies available may support the content to be taught and which pedagogical approaches are appropriate." (Webb, 2010). This additional component of knowledge has also been described by Koehler & Mishra (2005) as Technological Pedagogical Content Knowledge (TPCK), and is a term widely used by the research community.

Skills – Some of these were identified in the previous example experiment: Operational – Procedural - Pedagogical

The *ICT for IST* Project has been active in creating ideas for supporting professional development embracing the above elements of knowledge and skills. This is the model our project has used to structure thinking about the influence of ICT on pedagogy:

[Insert Figure 4]

1. For specific topic applications, we identify properties and learning benefits – these

contribute to expanding the *knowledge* base.

2. We identify and discuss the *skills* involved in teaching these ICT applications.
3. In addition, the project has given attention to *pedagogical* skills. Such skills are not entirely new, indeed established teaching skills play a vital role in securing learning gains, but they need to be adapted to exploit the affordances of software.

The results form the basis of a training 'curriculum'. The range of science topics for which this framework has been applied encompasses the biology, chemistry and physics curricula at secondary school level.

To explain how the resources provide a training curriculum we will take the example of the module entitled "*Electricity – Concepts and Circuits*"

The module guide contains these sections for teachers:

Introduction

- Background theory
- Pre-requisite knowledge
- Science concepts developed

Didactical approach

- Pedagogical context
- Common student difficulties
- Evaluation of ICT

The last of these 'Evaluation of ICT' is a commentary for teachers and forms the basis for developing TPCK. This section discusses each activity, considering how special features of ICT methods can contribute to children's learning and explains practical arrangements which achieve the best effect. The following extracts illustrate how the commentary attempts to identify learning benefits and give advice on pedagogical approaches:

[Insert Boxes 1, 2 and 3]

As a general principle, the teacher commentaries in the modules for all topics discuss how the activities with different software tools may be used in complementary ways, not only with each other but also with conventional practical work not involving ICT. The following is a summary of how the use of the tools may be integrated:

- Compare data-logging experiment graph with video record.
- Compare data from the model with experimental data.
- Compare graph with animated motion in a simulation.
- Compare a simulation with observations during a data-logging experiment.

These comparisons seek to exploit the affordances of ICT for each type of tool. They are content-specific and require careful examination of the learning objectives of each activity.

Progression and the challenge of change

As stated previously, the contents of the *ICT for IST Resources Pack* provide a foundation for building a training or professional development curriculum. They contain numerous and detailed descriptions, explanations and discussion of the knowledge and skills in topic-specific contexts. An intended outcome is that their use in teacher training courses should give teachers vision of the learning benefits of using ICT and ideas of practical strategies for exploiting the tools to the best effect. For in-service courses, a crucial aspect of this is to help teachers change their pedagogy.

John Gilbert (2010) has stressed that “Teachers’ pedagogic content knowledge (PCK) needs continuous development.” This suggests a metaphor of professional development as a journey in which the starting points for individual teachers might be different and the aim of any particular form of training should be to travel further on this journey. The following model sums up a progression in the use of ICT which has been confirmed by our experience of teachers attending a variety of training courses:

- **Non-user** – Teacher may have personal ICT skills, but has not taught with ICT in the classroom
- **Adopter –** Teacher uses ICT materials as they come, when they fit in with the teaching programme
- **Adapter –** Teacher modifies materials to suit different student groups and existing teaching style
- **Innovator –** Teacher develops and uses the ICT materials in a different context or novel mode of use
- **Creator / mentor –** Teacher creates new materials and/or fosters ICT use by colleagues

(Adapted from Dwyer et al., 1991)

However, from a teacher's or a teacher trainer's point of view, progression is not necessarily an easy process. It demands time and commitment and a willingness to believe that new ways can lead to better learning. Gilbert has emphasised the importance of challenging teachers to review the beliefs which drive their professional conduct:

> "The cornerstone for successful change in PCK must be that new knowledge can only be successfully coupled to new actions in the classroom if a teacher's underlying *beliefs* are supportive of the desired change. *Beliefs* are the key to change." (Gilbert, 2010)

Our belief is that this can be achieved through courses which are designed incorporating a reflective strategy. For teachers to be persuaded to review their beliefs, a course must provide not only hands-on experience, but also opportunities for serious discussion of the rationale for ICT-based tasks and to consider their match with teaching and learning objectives implicit in the normal school curriculum. One such approach could be to take one of the *ICT for IST* modules, like the Electricity module described previously, and discuss the pedagogical commentary with other teachers and the course providers. This might result in attempts to rewrite, amplify, augment or revise parts of the commentary, actions which will surely benefit teachers as engaging, developing personal insights and contributing to self-ownership. In the literature on professional development, Bishop and Denley (2005) advise that a collegial approach, engendering a sense of ownership by those undertaking the development, is generally the most effective. A practical example of an in-service course that explicitly promotes teacher ownership is described by Papaevripidou et al. (2011) who advocate that:

> ‘It is also equivalently important to give teachers the authority to act as *designers* of their own ICT-driven science curriculum materials, because engaging teachers in constructing a public artifact (e.g., their own curriculum) is a productive way to support their learning (Papert, 1991) and the transformation of their personal learning experiences into pedagogically potent curriculum designs.’ (p.2)

Ultimately teachers need to be *persuaded* to change their beliefs, and, with this in mind, discussion and self-reflection are more persuasive strategies than being lectured or simply told. As a profession, teachers have to be good persuaders of pupils. The challenge to teacher trainers is no less – to be good persuaders of teachers!

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Notes

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Innovative Science Teachers' in Warsaw, Poland on 28th October 2011.

The ICT for IST Project involved a collaboration of teacher educators in six countries, funded by the Leonardo da Vinci Programme within the Lifelong Learning Programme of the European Commission 2009-1-PL1-LEO 05-05046. All project materials are downloadable from the website: http://www.ictforist.oeiizk.waw.pl/

The examples use software published by www.insightresources.co.uk.

Table 1

Constructional	Informational
Software used for processing information - ICT serves as a tool for constructing new information and understanding Examples: • Data processing • Modelling • Simulation • Data-logging • Video capture	Software for presenting information – ICT facilitates novel methods of transmitting and examining ready-accumulated information Examples: • Internet • Multimedia • Visualisation • Instruction and tutorial

Figure 1

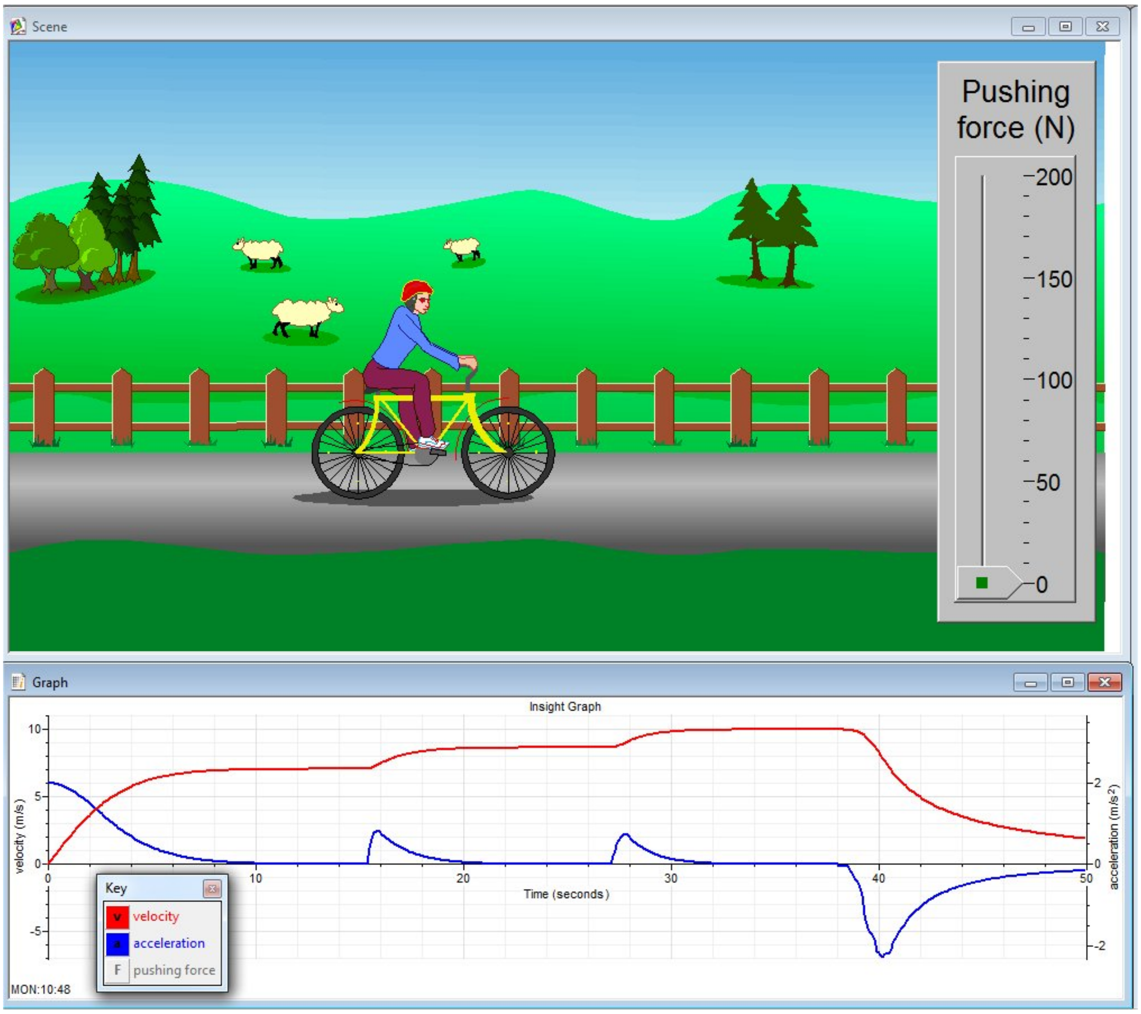


Figure 2

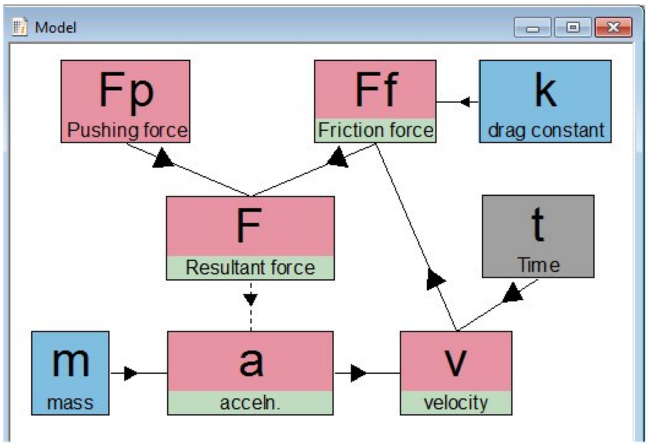


Figure 3

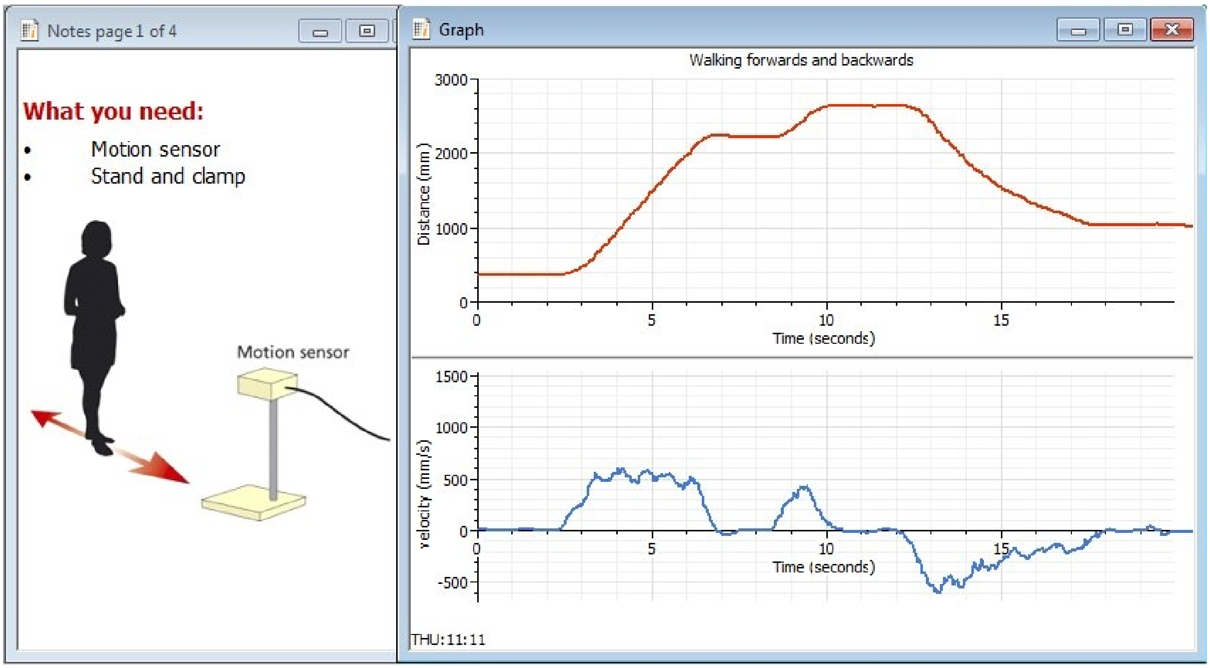
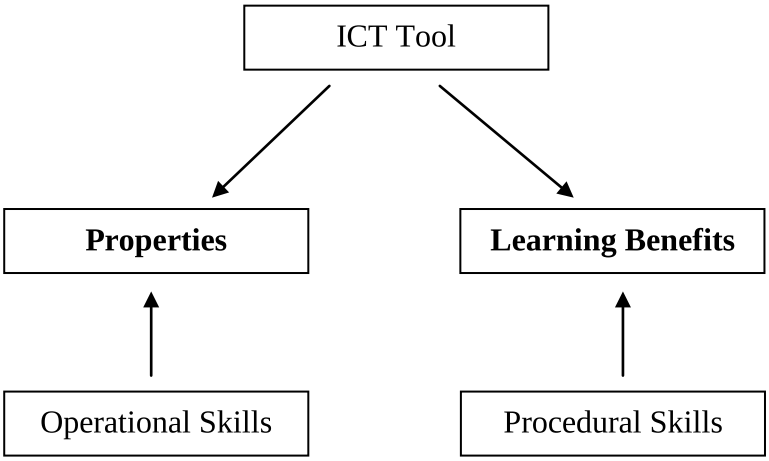


Figure 4



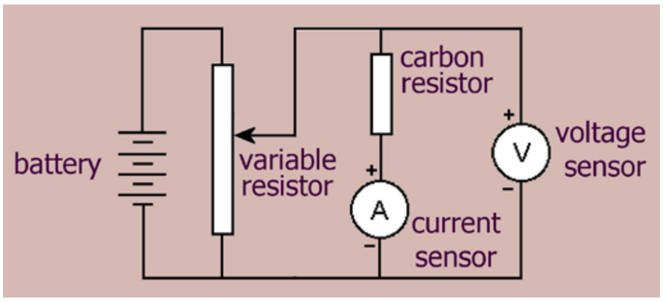
Box 1. Data-logging - see below

Box 2. Simulation - see below

Box 3. Modelling - see below

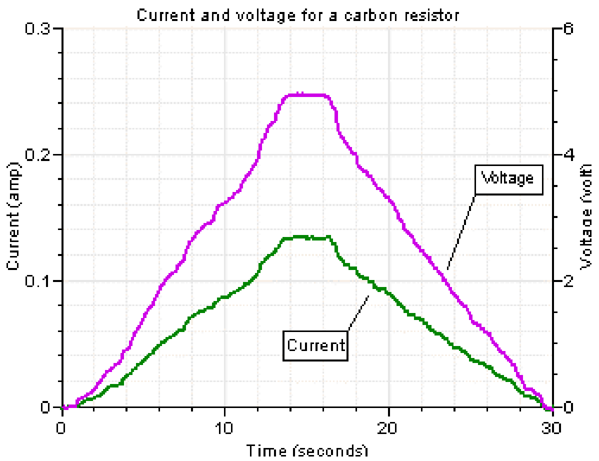
DATA-LOGGING

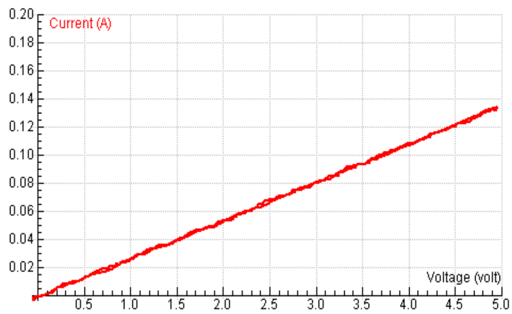
Experiment to investigate the relationship between current and voltage for a carbon resistor.



"The prompt display of the graph during the experiment allows attention to be immediately focused on trends, changes and comparisons."

"The activity presents both voltage and current readings plotted against time, with the advantage that changes in one are simultaneously imitated by the other. This provides a meaningful experience of a proportional relationship; cursory inspection of the graph shows that if the *voltage* is doubled, the *current* also doubles, and similarly for other ratios. This is a powerful introduction to the relationship in preparation for the conventional *current* against *voltage* graph. The latter graph, being a straight line, has an instantly recognisable shape, but the fact that this represents a proportional relationship can be nurtured through the analysing activities suggested here."





"It is implicit from the linear relationship that the resistance remains constant throughout the full range of current and voltage. Data-logging software makes this easily verifiable by calculating resistance and plotting this against voltage."

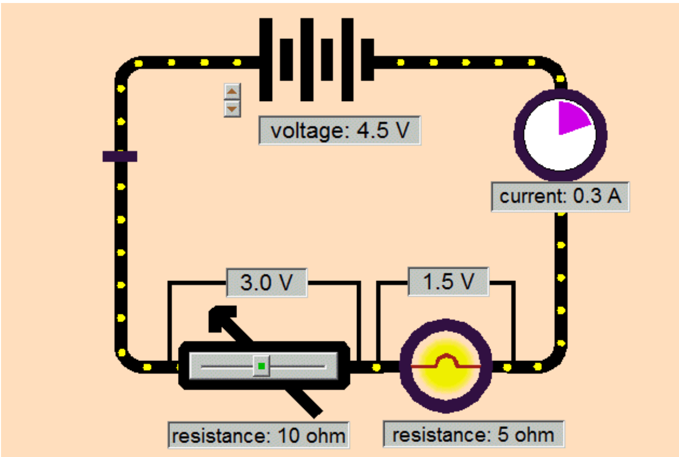
"Examples of non-ohmic components such as a torch bulb are readily investigated using the same circuit and experimental arrangement. Again the real-time plotting of the graphs allows results to be compared within a very short space of time."

"For the torch or bicycle bulb, results may be compared with the modelling activity which identifies the behaviour with the variation of resistance of the filament with temperature."

SIMULATION

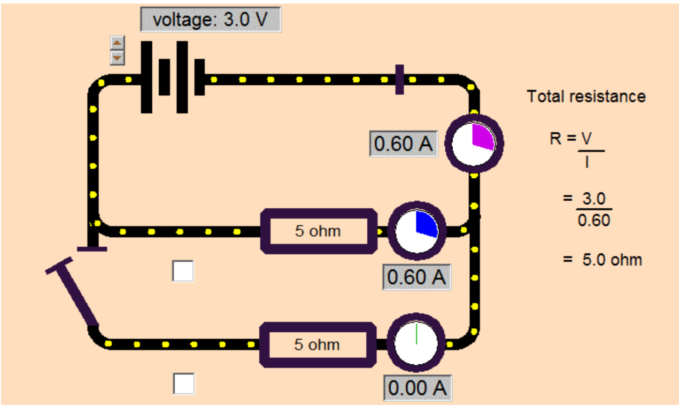
"The simulations presented here are best used as teacher demonstrations for facilitating class discussions of the concepts involved. Their use needs to be carefully managed and integrated with discussion in order to develop clear logical thinking. Random clicking on the various program features is unlikely to benefit thinking about subtle concepts about which pupils often have very confused ideas, so a structured approach is essential.

The simulations for this module have been chosen to illustrate the power of this type of program to facilitate discussion leading to an understanding of abstract concepts. They provide visualisations of the internal working of circuits which are invisible in real life. They achieve this by much symbolism and use of analogy which demands expert interpretation and guidance by teachers through structured argument. All the examples may, and should, be set up as practical laboratory activities, but the use of simulation saves much time, allows changes to be made rapidly, and measurements to be easily and accurately compared. Together with various visual displays such as moving charges, analogue meters and energy bars, the simulation environment greatly assists comprehension."



Circuit showing how the voltage applied by the battery is shared between the resistor and bulb in proportion to their respective resistance values.

"This simulation can be a powerful tool for developing an understanding of voltage, but it demands a carefully managed discussion with pupils."

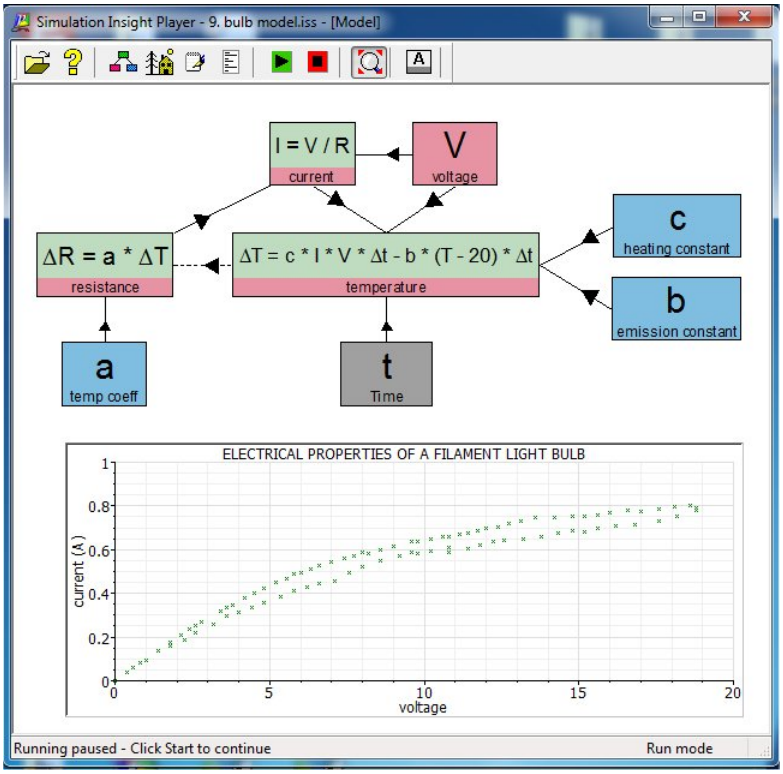


Circuit showing the calculation of resistance from current and voltage for various combinations of resistors in series and parallel.

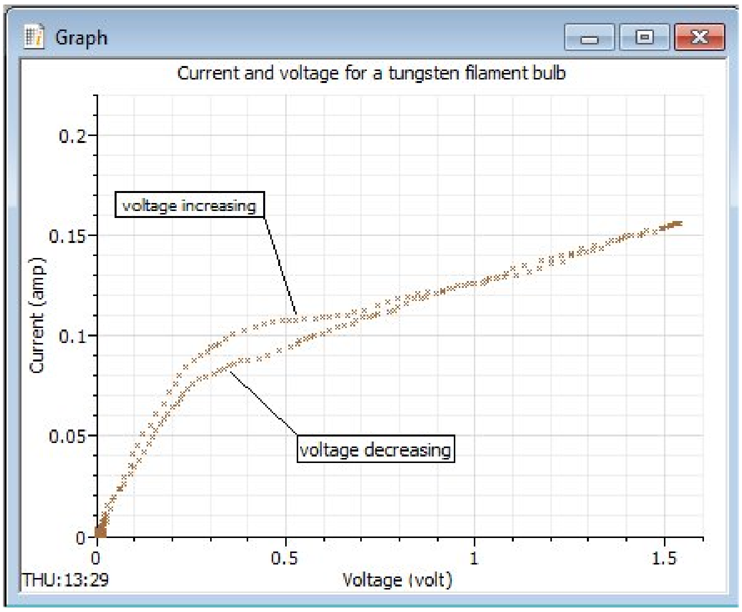
"The ease with which different combinations of resistors may be selected, saves considerable amounts of time, ensures accuracy, and facilitates rapid comparison. A useful teaching tactic is to ask pupils to predict the likely current or resistance before each test setting."
"The method of calculation of the total resistance is completely transparent to pupils, but the results always seem to be surprising: more resistors in parallel give less resistance!"

MODELLING

"The purpose of the modelling activities is to give pupils an insight into the physical and mathematical basis of the calculations performed by the model. The essence of modelling is to experiment with adjusting the model so that it gives results which best match data from real experiments. The results from models may be compared directly with those obtained from the data-logging activities."



A model for calculating the current – voltage characteristic of a tungsten filament torch bulb. The graph shows the data generated as the voltage is steadily increased to a maximum value and then steadily decreased.



Data obtained from the data-logging experiment with a torch bulb. As with the model, the voltage was initially increased and then decreased.

The non-linear graph arises due to the temperature change of the filament with a consequent change in resistance. The model shows that theory about heating and cooling and their effect on resistance can predict a similar graph. It also predicts the loop shape due to the effect of time on the balance between heat generated and heat lost to the surroundings.

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