INFORMATION TECHNOLOGY FOR UNDERSTANDING SCIENCE (IT for US)

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ABSTRACT

The principal aim of the IT for US Project is to present teachers with a vision for the use of ICT in science teaching which exploits the qualities of software tools for developing conceptual understanding of scientific phenomena. A series of activities have been devised which illustrate how the uses of data-logging, modelling, simulation and video capture may be integrated and how the comparison of results from different methods facilitates the type of thinking and discussion which leads to better understanding. A common core of activity providing numerous links involves the analysis of data in a graphical format. The potential of software for securing learning gains depends crucially on the pedagogical actions of the teacher, as is the case in any conventional teaching context. However, in the new context using ICT, teachers' pedagogical understanding requires updating to exploit the new methods of investigating phenomena and visualising and analysing data. The pedagogical commentaries developed by the project attempt to fulfil this need.

KEYWORDS
Constructivism, data analysis, data-logging, modelling, pedagogy, simulation, video capture

INTRODUCTION

The emergence of Information and Communication Technology (ICT) in recent years has challenged virtually every segment of society to reconsider its traditional practices and methods. The result has been to transform many industries, media, communications, entertainment and the conduct of business and commerce in general, both nationally and internationally. In education also, the effect of ICT on the perceptions of future potential and the ongoing discourse has been impressive; there exists a wealth of applications for facilitating, supporting and enhancing the quality of teaching and learning. Nevertheless, in many countries of Europe, there are still many educational institutions in which the potential of ICT has not yet been fully realised. This indicates a serious need for in-service training of teachers in ways that can promote better understanding of the potential for ICT.

An important component of ICT is the computer, but its application as a useful tool depends crucially on the software functioning within it and also on the design of activity sequences that can scaffold students to develop scientific thinking and conceptual understanding.

EDUCATIONAL SOFTWARE

Through suitably designed software, the computer can function as a calculator, information store, data processor, audio-visual presenter, telecommunications terminal, word processor, simulation, emulation and modelling medium. The broad range of educational software falls into two main categories. Papert (1999) has described these as the 'informational' and 'constructional wings':

Constructional wing
This describes the processing of information in which ICT serves as a tool for constructing new information and understanding. Within the constructional wing, the strands relevant to science are:

- Data processing - computations, sorting, conversions, etc.
- Modelling - mathematical representation of scientific phenomena
- Simulations - virtual experiments
- Data-logging (Microcomputer Based Laboratory) - physical measurement
- Video-capture techniques

Informational wing
This describes the presentation of information in which ICT facilitates novel methods of examining ready accumulated information. Within the informational wing the strands relevant to science include:

- Internet - access to informational sources throughout the globe
- Multimedia - video presentation
- Visualisation - the use of graphics and display tools to provide insights into concepts which are difficult to represent with conventional textbook diagrams and presentation technologies.
- Tutorial and instructional programs

A wealth of material is already available for activities employing strands in the informational wing and will not be discussed further here. It may be argued that, in the world of education, such activities have received overwhelming attention to the neglect of activities in the constructional wing. In an attempt towards a fairer balance, the work of the *IT for US* Project has focussed primarily on activities in the constructional wing. One reason for this choice is the relevance of these activities to the constructivist view of learning, which has had the dominant influence on the design of contemporary science curricula. The essence of this view is the recognition that for children to learn, they have to be actively involved in the learning process; they construct meaning by the process of interaction and enquiry (Vygotsky, 1978, Engeström, 1987). This is particularly relevant to science education with its traditional emphasis on experimental, hands-on activity in science laboratories. Successful pedagogy with laboratory work strives for understanding by making links between theory and practice. Herein lays a crucial role for the teacher and, when ICT tools are introduced, the need for reinterpreting this role becomes an essential demand in teacher preparation programmes aimed at promoting the use of ICT. To provide vision of how the teacher's role can influence the successful outcome of ICT activities is the chief rationale for the *IT for US* Project.

Before examining the principles underpinning the teacher's role, it is appropriate to review the potential learning benefits associated with the four main software tools which serve constructional activities in science: Data-logging, modelling, simulation and video capture.

DATA-LOGGING

The term 'Data-logging' describes the process of gathering and recording measurement data from *sensors*. These are devices whose function is to detect a physical variable and convert it into an electrical signal. Sensors take the place of instruments such as thermometers and voltmeters used in conventional practical work. The process of measurement, as such, involves connecting the sensor to a *data-logger* or *interface* which converts the electrical signal into a digital code that is either stored inside the data-logger for later retrieval or is sent directly to a computer, usually via the *USB port* of the computer. Compared with the other software applications described here, the requirement for additional hardware equipment means that data-logging demands the application of practical skills as well as skills for analysing and interpreting data.

To justify the use of data-logging, it is important to recognise several specialised features which have not been hitherto available in conventional measurement methods. Such special features provide opportunities for improved learning, provided the teacher is aware of them and designs the learning activity appropriately to exploit them. Here is a summary of specialised features and their respective potential learning benefits:

- The measurement process is automatic: This lowers the level of operational skill required, saves time which may be put to more useful purpose, allows much more data to be collected and frees pupils to make observations of the phenomenon being studied.
- The rate of data collection is available over a wide range of frequencies: Very fast and very slow rates of collection provide new contexts for gathering data and expand pupils' experience of phenomena.
- Remote logging - data may be collected and stored independently of the computer: This allows the collection of data in a wide variety of environments, including outdoors, and facilitates collection over long periods of time, beyond the normal scope of lessons in school. This increases the amount and types of primary data available to pupils.
- ‘Real time’ reporting - data may be presented in a graph whilst the experiment is in progress: This makes data collection an interactive process whereby direct observations may be immediately compared with the graph, encouraging thinking about the data and representations.
- The accuracy of measurements and recording is superior to manual methods. The reduction of errors in taking readings results in better quality information, which potentially improves the clarity of relationships between variables.

MODELLING

At first sight, many modelling activities involve the manipulation of formulae and their subsequent use for calculation; a mathematical model is used in the first instance to describe a phenomenon and then to predict new information about the phenomenon. However, the purpose of modelling is to aid thinking about the phenomenon concerned and an essential learning aspect of the modelling process is to forge links between the phenomenon, previously understood principles and the model itself. A model may consist of one formula or a sequence of several interdependent formulae and it is often tested by comparing its calculated data with experimental data. Pupils can use the newly generated data to test their theories and knowledge about a phenomenon. A key feature of modelling activity is the process of editing and altering a model to study the change of behaviour. Exploring alternative models or diverse versions of models of the same phenomenon helps to develop pupils' understanding.

SIMULATIONS

Unlike modelling programs, which are generic in character, simulations usually portray a particular phenomenon or experiment. They facilitate virtual experiments in which variables and parameters may be adjusted and the effects studied. It becomes possible to represent conditions well beyond the scope of real experiments, and in this respect a simulation can extend opportunities for investigation. In this virtual environment, pupils can perform otherwise dangerous, difficult, expensive or specialised experiments. Such experiments yield ‘clean’ data without the ‘noise’ of experimental error. It is difficult to describe a general type of simulation because each simulation tends to have a unique purpose. It is common for simulations to be presented with attractive graphics that are often animated making the context easily assimilated by pupils. Simulations can be useful for the visualisation of difficult concepts.

At the heart of every simulation lies a mathematical model controlling all the relationships between the variables involved. For most simulations, the model is built into the program and access to it is not available to users. However, for those programs that do provide access to the model, there are valuable learning opportunities for scrutinising the model and questioning its assumptions.

VIDEO-CAPTURE

The video camera has become a common domestic article and it is ideal for recording experiments involving physical movement. Slow playback, frame by frame, allows the motion of an object to be studied in detail. Better still, software allows distance-time data to be extracted and displayed as graphs. In this form, the whole repertoire of graph analysis aids may be employed to investigate the properties of the motion. The video technique opens up a wide variety of contexts for studying motion outside the classroom: sports of all kinds, transport, amusement parks and so on.

ICT TOOLS FOR CONSTRUCTING KNOWLEDGE AND UNDERSTANDING IN SCIENCE

The software tools reviewed above each serve science activities in the constructional wing described by Papert (1999). In order to realise the learning benefits afforded by the tools, it is crucial that the threshold of technical skill needed to use them is sufficiently low to allow the primary focus of activity to be on the science phenomenon under investigation and avoiding distracting preoccupation with the technology itself. After steady development for several years, modern versions of the software tools have now reached a state of maturity which permits this. The particular features which have facilitated this are summarised thus:

Table 1.

Data-logging software	• Sensors connected to the interface are automatically identified and calibrated by the program. • Graphical display of collected data allows axes to be easily assigned and scaled automatically. • A variety of tools are available for analysing data and for deriving new data. • Screens may be customised to the needs of particular experiments.
Modelling software	• Intuitive methods for defining relationships between variables. • Inputs and outputs to models are linked to graphical controls and displays. • Simultaneous graphical data display during computation aids understanding. • Controlling the speed of computation assists the study of the behaviour of a model. • Animated images linked to a model assist the visualisation of the underlying mechanism.
Simulation software	• Simulations of physical experiments are not bound by limitations normally constraining real experiments, allowing greater scope for (virtual) investigation. • Visualisation of phenomena through animated images is good for motivation and engagement with the concepts involved.
Video-capture	• Video recordings of experiments involving change or movement may be analysed to yield graphs that may be used for analytical study.

The handling of numerical data is a core activity for all these software categories: data-logging and video capture software facilitate the collection of data; modelling and simulation software generate new data. Throughout, a common goal is the analysis of data, mainly through the use of graphs for which a large repertoire of tools exist in the software. In practice, individual software packages incorporate features of two or more of the software types listed above. Activities developed by the IT for US Project focus on the use of the following software packages:

- *Coach 6* developed by the AMSTEL Institute (Amsterdam Mathematics Science and Technology Education Laboratory) at the University of Amsterdam, The Netherlands. It is widely used throughout Europe as a comprehensive system for computer measurement, modelling and control. The program provides an environment allowing simultaneous use of a variety of tools: explanatory text, pictures, videos, graphs, tables, numerical displays, models and programs for control systems.

As an authoring system, it enables the teacher to create multimedia activities for pupils. For data-logging, it supports a variety of hardware systems including the Coach II interface.

- *Datalogging Insight and Simulation Insight* developed at the School of Education at the University of Leicester, England. They are widely used throughout schools in the United Kingdom. The programs offer the integration of data-logging, simulation and modelling activities through a common user interface built around a versatile graphing facility incorporating a suite of tools for analysing data. The *Datalogging Insight* program interfaces with a wide variety of different manufacturers' data logging hardware systems such as LogIT, Data Harvest and Coach II. The *Simulation Insight* program provides an authoring system for creating, testing and running simulations of a wide range of scientific phenomena. The program gives complete access to the mathematical model, which drives the simulation. It is thus possible to modify, redefine or replace the model, allowing pupils to investigate the theoretical assumptions upon which the model is based.
- *Modellus* developed at the Faculty of Science and Technology, Nova University, Lisbon, Portugal. It has been adopted as a modelling tool by many curriculum schemes in Europe and the Americas, is a software program that enables students to use mathematics to create models interactively and to build simulations based on these models. Modellus can be used as an exploratory or authoring environment. Entering a mathematical model in Modellus is like writing mathematical equations on paper. The program provides multiple representations of mathematical models by allowing them to be viewed concurrently as animations, graphs, and tables. Modellus models are interactive; while a simulation runs, students alter variables to see the effects on the animations, graphs, and tables.

The four types of software discussed here offer distinctive but complementary methods of engaging with the science of a chosen topic. Data-logging and video-capture record data from real experiments, simulations offer extended investigation in an environment of virtual experiments, modelling can develop thinking about relationships between variables, their mathematical description and the application of basic scientific principles. All types of software share the common theme of exploiting the resources of graphical representation and the associated extensive repertoire of tools for analysis and interpretation. Investigating data in the form of a graph forms a common core of activity and facilitates an integrated approach to using the different types of software. It is an explicit aim of the IT for US project to demonstrate how this integration may be achieved.

IT FOR US PROJECT MODULES

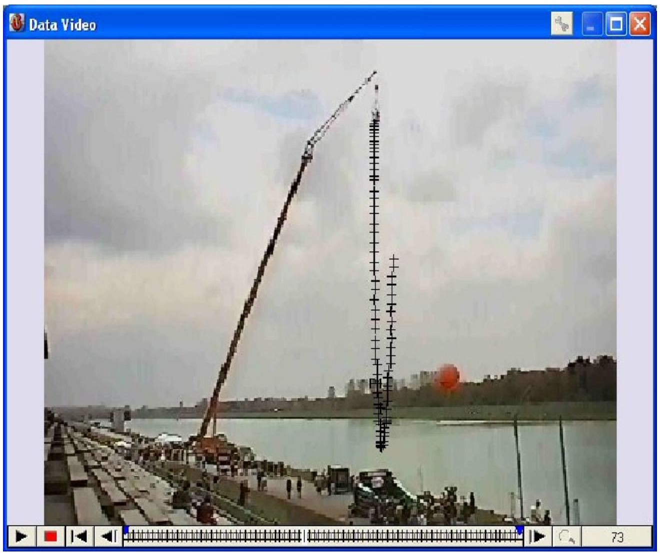
Exemplary teaching materials were developed for twelve topics covering biology, chemistry and physics. The physics topics included Oscillations, Graphs and Trajectories, Vectors, velocity and displacement, Cooling and change of state, Electricity – Concepts and circuits, Bungee jumping and Thermal energy. Each module consists of Pupil Activity sheets giving instructions for performing the tasks and a Teachers' Guide providing background information, advice on teaching approaches, and a commentary on the potential learning benefits of the activities. The intended audience for the latter is not only teachers, but also teacher trainers who may use the materials for organising courses, seminars and workshops. The modules contain didactical advice including explanations of the practicalities of performing the activities, the rationale informing their design and a pedagogical discussion of the ICT methodology which is summarised in the final section of this paper. To illustrate the didactical approach adopted, the example of the Bungee jumping module will be described in outline.

The topic of a bungee jump was chosen partly to illustrate how physics may be learnt from an out of school context not normally specified in mainstream curriculum but is likely to be of great interest to students. The following activities are described:

- *Video measurement* - measurements on a video of the bungee jump allowing analysis of the bungee jumper motion.
- *Data logging* - laboratory experiments to measure force during stretching of the elastic with different masses and force encountered by jumpers on different bungee cords.

- *Simulation* – an animated graphical interface allowing parameters to be adjusted and their effect on the motion of the jumper to be studied
- *Modelling* - a mathematical model to describe the motion of the bungee jumper.

The video clips of bungee jumpers provide a stimulating introduction to the topic. Using *Coach 6* software, the sequences may be analysed frame-by-frame to give distance-time graphs of the motion. Further graphs showing velocity and acceleration may then be obtained and the relationships between the motion variables discussed.



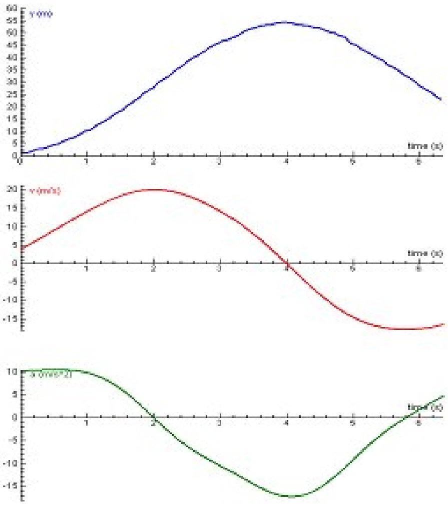
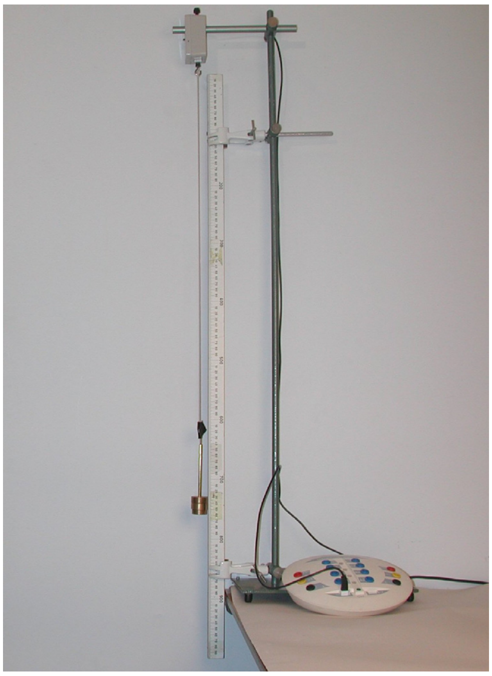


Figure 1a. Bungee jump video with analysis points added
Figure 1b. Distance, velocity and acceleration graphs

The data-logging experiment (Figure 2a) emulates the behaviour of the bungee elastic cord in the laboratory and provides real data for the tension in the elastic. These data may then be compared with the motion variables graphs obtained from the video analysis (Figure 2b), leading in particular to a discussion of the connection between the forces involved and the acceleration.

The simulation (Figure 3) provides a virtual environment in which the investigation of the relationships between variables may be further extended by allowing parameters to be varied beyond the constraints of real bungee equipment or its emulation in the data-logging experiment. Thus the user can study the effect of varying the jumper's mass, or the cord length or the elastic compliance.

The model shows how theory is applied to describe the motion mathematically. The model generates data which may be compared with that collected in the previous activities. As with the simulation, parameters may be adjusted to vary the results which show up as differently shaped graphs. The *Coach 6, Modellus* and *Simulation Insight* software (Figure 4) offer three different methods of building models. The latter program gives access to both the graphical interface and the model which generates the data. Part of the learning value of a modelling activity lies in the way in which the model allows a sophisticated phenomenon to be broken down into simple elements, consisting of basic principles.



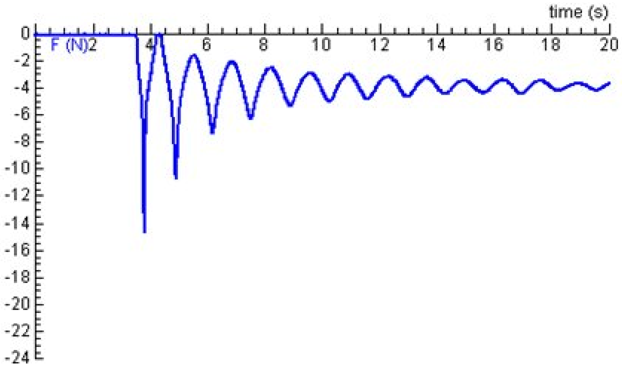
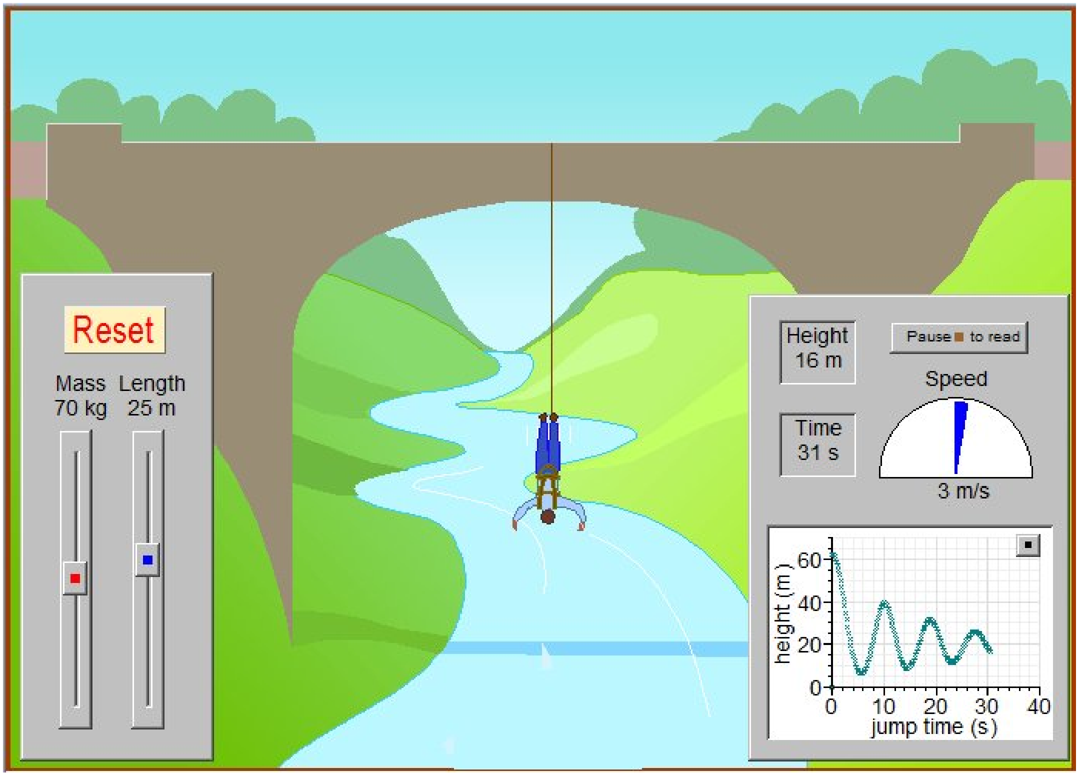


Figure 2a. Data-logging experiment, measuring tension in the elastic cord using *Coach 6*.
Figure 2b. Logged data: Cord tension varying with time.



Mass 70 kg

Length 25 m

Height 16 m

Time 31 s

Speed 3 m/s

Figure 3. Bungee jump simulation using *Simulation Insight*.

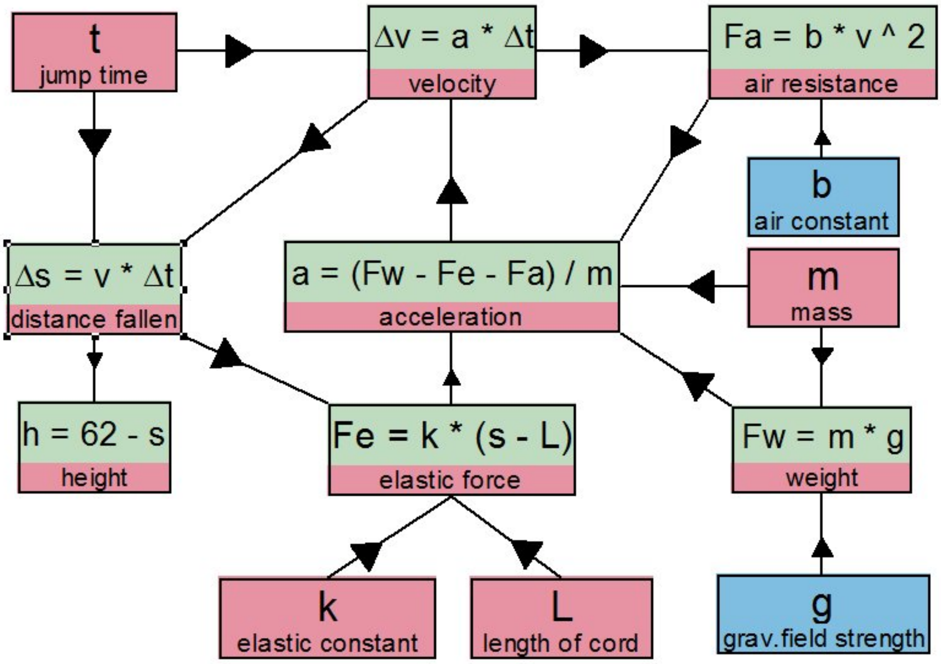


Figure 4. Model of bungee jumper motion, using *Simulation Insight*.

TEACHING WITH ICT

The effective use of the software for teaching and learning requires the development of skills, some of which are specific to software and some which are already familiar in the practice of science (Newton and Rogers, 2001). In planning skills development, it is helpful for teachers to consider two types of skill with software:

- *Operational skills,* which concern the manipulation of the computer hardware and knowledge of the features in the software. Examples include the setting up of sensors and interfaces, the setting up of graph parameters, the use of analysing tools and the loading and saving of data files.
- *Procedural skills,* which concern the manner in which the software tools are applied for the purpose of achieving learning benefits. A dominant aspect of these skills is the development of an inquiring approach to the analysis and interpretation of data and to making links with previous knowledge.

At the beginning of secondary schooling, most pupils already have a confident command of operational skills associated with the *Windows* user interface, so the main training requirement in science lessons is to add to these the skills needed for the specific hardware and software. Much of this may be achieved through individualised instruction through the use of worksheets or with tutorial software built into the programs. For the acquisition of procedural skills however, the task is much more subtle and the role of the teacher is crucial. Procedural skills involve insight, understanding, judgement, purposeful inquiry and cognitive effort, attributes that can only be acquired through practice and habitual questioning. By example, the teacher can demonstrate strategies for appropriate and purposeful use of the software tools from which pupils may model their own methods and approaches.

For the teacher, there are further *pedagogical skills* that contribute to the effectiveness of the activities:

1. Clarity of learning objectives for each activity.
2. Understanding of the special value of the ICT tools and exploiting their full potential in purposeful ways for learning.
3. To manage the activity in a way that promotes ‘appropriate’ rather than ‘indiscriminate’ use of ICT.
4. To integrate the learning from each activity and to take corrective measures in order to facilitate the development of pupils’ understanding of the topic.

The development of the last of these is a particular aim of the *IT for US* Project, and the activities presented in the topic modules have been specially selected to illustrate how integration might be achieved. Comparisons of the observations and results of each activity form a central role in this integration process. For example:

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

In these, the graph is a key tool in facilitating comparisons and interpretations, and skills with graphs generally provide a common thread in *IT for US* activities. In software, the graph is such a versatile tool it is an ideal resource for supporting pupils working in an investigation mode, formulating their own questions, selecting their own procedures and testing their own hypotheses.

The management of the classroom setting also has an important influence on the successful integration of activities. When access to computer equipment is scarce it is likely that the teacher will wish to present the activity as a demonstration in a didactic manner. In this mode, the teacher can give strong guidance to pupils' thinking about the comparisons between the activities; by example, the teacher can model an inquiry style of thinking. Alternatively, pupils could perform the activities in small groups of three or four pupils, each group engaged on a different activity. Integration might be achieved by each group making a presentation of their results to the whole class. In chairing these presentations the teacher can prompt discussion of the significant findings of each group.

It is worth considering that all the activities may be used in a variety of learning contexts; it is not necessary to consider their mode of use exclusively as a first experience of the topic. For example, the simulation or video capture activities could be used as a briefing before a practical experiment; simulation and modelling might be used as a means of extending an investigation, as a revision of a previous activity, or for distance learning. Although the activities have been designed to draw on the different tools in order to provide complementary experiences, it is not essential to use all four of them; two, three or four ICT tools might be chosen according to how well they suit the needs of teachers and pupils in a particular context. In varying conditions between schools and within schools at different times of the year or different stages in the curriculum, needs and appropriateness are likely to change; for example, data-logging equipment might not be available at the time of need, an individual pupil might need a revision or extension activity, an enrichment activity might be required to occupy some spare time, a quick activity might be needed if time is scarce. The overlapping features, such as graphical presentation, between the activities allows them to be used to a certain extent as alternatives, but their distinctive features also allow them to be used as complements to each other.

It becomes evident that the use of ICT in teaching provides many new opportunities: new tasks, new ways of teaching and new ways of learning. These are discussed in more detail in the *IT for US* modules. It is inevitable that ICT changes methods of teaching and learning. In particular, a more pupil-centred style of teaching compatible with the constructivist view of learning gains appropriateness. However, it is also true that the success of ICT depends upon the actions of the teacher. It is important to recognise this mutual dependence; ICT affects teaching and teaching affects ICT.

In this discussion it has been implicit that the ICT activities have been embedded in the science curriculum. It is a main principle of the *IT for US* project that ICT has great potential for developing pupils' understanding of science and, for this to be achieved, ICT methods must be incorporated in the teaching of science topics. This may be difficult in those countries where informatics is regarded as a separate discipline which is taught in a separate part of the curriculum from science and other subjects. It is hoped that the materials and arguments presented by the project may be an agent for change and source of encouragement to science teachers to realise the benefits of ICT for improving pupils' understanding of science.

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