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Computer-assisted teaching and concept learning in science: the importance of designing resources from a pedagogic model

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Abstract:

Computers and related information and communication technologies (ICT) are increasingly being employed in teaching at school and college level. Like any new educational technology, computers have strengths and limitations, and it is important that computers are used to support existing educational aims when they are appropriate tools, rather than simply being adopted to do what they are good at because ICT is seen as intrinsically 'good'. In science teaching, computers offer a number of useful properties, both related to their use in data collection and analysis, and their ability to offer high quality simulations. These modes of use offer much to support the classroom teacher. However, computers are increasingly being seen as suitable tools for 'delivering learning' in individual study as a supplement to, or even an alternative to, the teacher. Whilst this offers more flexibility - in where and when studying can occur - resources intended to 'teach' learners when the teacher is not present are a different proposition to resources provided as tools for the teacher to employ flexibly to support their own teaching. Conceptual learning in science is well recognised as often being problematic even with motivated students and skilled teachers. This chapter considers the challenge of producing materials to support conceptual learning in science, and the type of pedagogic models that are needed for successful computer-assisted teaching of science. As an example, the chapter discusses the pedagogic model employed in developing learning material in physics for use in further education colleges in England, and the responses of students to the resources.

Key words: **resource-design**; **interactivity**; **conceptual change**; **science teaching**; **scaffolding learning**; **instructional model**; **constructivism**

Computer-assisted teaching and concept learning in science: the importance of designing resources from a pedagogic model

Introduction

Computers and related information and communication technologies (ICT) are increasingly being employed in teaching at school and college level. Where computers may have been seen as something of a novelty some decades ago, ICT is now seen as a normal part of the resources needed for a properly equipped classroom in much of the 'developed' world (Becta, 2008; Ofsted, 2009). Data projectors are now the norm in many classrooms, as are 'interactive' whiteboards. Computers for student use are common in teaching rooms, and so are suites of machines for teaching staff to book or as part of the provision of independent learning facilities.

Like any new educational technology, computers have strengths and limitations, and those that have an interest in the sale and adoption of such equipment clearly wish to focus on the strengths. Without in any way undermining such strengths, it is important to recognise potential issues about the increasing use of ICT in classrooms.

One such issue is that of the nature of what computers are good at in relation to what classroom teachers need to support them in their work. There is a danger of focusing upon the strengths of computers (e.g. their processing speed; their storage capacity; their networking potential) and developing applications around these strengths, which then need to be 'sold' to schools without consideration of what kinds of tools teachers want. This is perhaps understandable and maybe even inevitably, but has potential to distort teaching. If substantial investment is made in new ‘kit’ and associated applications – designed to fit the strengths of the hardware – there will be pressure on teachers to use the resource: even if it may not do exactly what they need. This is not such an unlikely scenario when the pressure to include and adopt new technology comes from national government-led initiatives rather than teachers themselves (Becta, 2009a, 2009b). An obvious need here is for end-users to be very much involved in the design of educational resources (whether hardware or software). However, even when this happens, there is a likelihood of enthusiasts among teaching staff getting involved, who may not be typical of their colleagues. Enthusiasts will tend to have not only a level of high commitment, but also higher levels of skills and knowledge, and most importantly the confidence to be prepared to persevere with an innovation in the face of initial setbacks.

Ultimately, teaching resources should allow teachers to do better the things that they feel meet educational aims and objectives, rather than just offer a good way of doing something simply because it is possible with the technology.

This seems to have been a very real issue in the early mass introduction of computers into schools: with equipment in many classrooms being seldom used because there was little that teachers wanted to do with it (or at least because the things it could do that teachers wanted to do, needed machines to be employed in modes that were not viable with the ratio of machines to pupils in a classroom). However, it should be recognised that as applications have become available which *do* support what teachers want to do, this has become much less of an issue.

A related problem is the ‘cost-benefit’ aspect of teachers learning to use new resources. A busy teacher working with challenging classes may well see potential value in doing things differently. But learning new teaching approaches – in terms of learning to use the technology well enough to adopt it whilst multi-tasking in a busy classroom; in terms of teaching the pupils the skills involved; but just as much in terms of adapting pedagogy to best apply the new approach – takes time and effort. Moreover, it is almost inevitable that there will be a learning-and-practice period where things will not be done as well using the unfamiliar approach as they were by more traditional means. Teachers have to not only believe that change is ultimately worthwhile, and should be undertaken 'at some point' (often an easy commitment), but also that they have the capacity to take on the challenge 'now'. In practice, 'now' seems to always be a busy time for teachers, and there is usually a perceived 'easier' time somewhere on the temporal horizon. Professional development support is obviously a key requirement here (Davis & Varma, 2008; Warwick & Kershner, 2008).

Use of ICT in the classroom

A key use of computers in many classes is to access the Internet. In some ways this is an excellent exemplar of what ICT does well. Traditionally classrooms may have had some reference books - in my own school teaching days I maintained a modest library of science books in my teaching lab - but this is inevitably a limited resource. The school or college library offers more options. However, referring to library books during a lesson poses logistic problems. Time spent moving back and forth between classroom and library is not efficient. In many schools, allowing pupils to freely move around school in this way unsupervised would be frowned upon or even forbidden anyway. Yet even aside from these concerns, the school or college library is likely to have a limited range of up-to-date titles on any particular topic.

The Internet offers an ideal step forward in this regard. Through the Worldwide web (www), any classroom computer can access information on just about any topic; and including the most up-to-date postings. (At least, to the extent that the school computer office does not restrict access to resources – a common complaint of UK teachers is that restrictions meant to prevent connection to sites deemed inappropriate for school children often also act as barrier to ready access to useful resources.) This facility has rightly been adopted in many classrooms, in science as in other curriculum areas. However, as teachers soon realise, whilst computers are very good at accessing information, pupils are often very poor at selecting, critiquing or synthesising sources. The Internet offers a vast – indeed effectively unlimited - resource provided that the discriminating user can apply quality control. Teachers soon find that whilst Internet access is a very good way to keep pupils occupied, and, sometimes, even on-task, it is only an efficient use of student time once some important higher level skills are acquired. This certainly does not suggest the internet should not be readily available to pupils: many have it at home and are accustomed to being able to search for information at whim (and it is important that resources at school should not be obviously inferior to those at home); and without doubt the critical and effective use of such ICT is a major life skills that all school leavers should have acquired. However, it shows there is a cost to effective use of the resources that must be paid to get the most from the facility.

Another innovation that has been widely adopted is the use of the ‘data projector’, often in conjunction with an interactive whiteboard (IWB). The data projector allows the teacher to prepare material on the computer and then present it in class. This could be seen as a digital update on the overhead projector (OHP), an earlier innovation in educational communications technology that allowed the teacher to bring to class pre-prepared acetate 'slides' to show during the lesson. As always, the technology may be used in conservative or innovative ways.

A chalkboard allows a teacher to write out their notes for students to copy, rather than having to read them aloud. Yet a teacher who simply came into class and wrote out their notes on the board would hardly be considered to be teaching in the usual understanding of the term – although generations of university students might well recognise this form of 'educational' technique! The good teacher used the chalkboard in a more *interactive* manner: in the right hands 'chalk and talk' can be effective and engaging.

The OHP could also be used just as a 'high-tech' means of notes-transfer: but also had new potential. Having pre-prepared notes on slides makes life in the classroom easier for teachers, but offers little advantage over a chalkboard to a pupil simply asked to copy down the same information as could be written on a board. However, the OHP offers new affordances. A detailed diagram that would take considerable time to draw on the board could be prepared on several layers of acetate sheeting, allowing an explanation to be 'built up' with the displayed figure itself. Overlays can also be used to present incomplete information to test student understanding (cf. the modified 'cloze' procedure commonly used in teacher hand-outs and student textbooks), and material from textual sources that were too small to be seen from all around the class could be photocopied to acetate for projection so that they were visible to all the pupils at once.

The data projector in turn could be seen as little more than a digital version of the OHP, and even in this regard it offers some advantages – neater text; ability to include diagrams and photographs sourced from the internet etc.; ability to reveal information point by point so as not to overload pupils. (Of course seasoned OHP users achieved much the same effect with a paper sheet being moved down the acetate as it was revealed – but the data projector does not suffer in the same way from the potential effects of draughts.) Yet the real potential of new technology, though, must be in *enhancing pedagogy*. Where IWB are simply used as display screens for data projectors, they could as well be effectively and cheaply replaced by the application of some matt white paint. Where the real interactivity of the IWB is used, teachers are able to explore the enhanced pedagogy that new technology offers. New technology actually supports innovation *not* by being novel kit, but by enabling novel application. In the case of IWB the potential would seem to lie in develop the dialogic aspect of teaching and learning (Hennessy, Deaney, Ruthven, & Winterbottom, 2007; Warwick & Kershner, 2008), something that has been recognised as key to student learning in all areas, including science education (Mercer, 2004).

Using technology to teach science

It has been claimed that "despite widespread use of technology by scientists across many disciplines, computers and network technologies are often underutilized and poorly integrated into core science education activities" (Butler Songer, 2007). This is a great shame as in the science classroom, new technology has offered a number of especially appropriate new resources for teaching. One of these areas is data-logging: using computers to collect and store experimental data.

There is immediately an issue that should be addressed here, of possibly excluding pupils from essential aspects of the scientific process. Making observations and recording measurements is a part of much empirical work in science. In many areas of science these processes are often now automated: computers collect the data, store ('log') it, and then offer various ways of displaying it. Indeed, often the raw data is not actually examined by a human being at any stage; as the data is 'treated', or even fully analysed, before being presented to the scientists themselves. This creates a question about whether we want science education to be authentic – like working in real modern laboratories – or about understanding principles and processes, in which case it may be a mistake to have machines undertake key stages in data collection and analysis. Of course, this is not *really* an 'either/or' question: we want students to both understand the processes and experience some degree of authenticity. The question then is *when* it makes good educational sense to use technology to automate school science practicals.

An immediate answer is: not until pupils have had some experience of simple practicals where they can be involved in all stages of the data collection and analysis processes. It may make sense for pupils to undertake a relatively straightforward practical 'by hand', before repeating the same basic practical using a data-logger (or data-logging computer). This would allow the pupils to best appreciate precisely what the data-logger is doing, and also ensure enough familiarity with the specific science and practical to allow them to focus primarily on the data-logger as a tool they can use. Some of the issues here reflect the debate in mathematics education around if and when pupils should use electronic calculators rather than calculate in their heads (and no doubt much the same debate was previously held in the era of slide rules and log tables).

Once students are used to the data-logger, it can then be used in subsequent lessons when it offers a specific advantage. Examples would be when observations need to be made over extended periods (e.g. set-up in a lesson, and left overnight), or with higher frequency than pupils could achieve (for example with fast changes), or when several probes are used to take simultaneous readings etc. The possibility of watching graphs plotted in real time, *and* being able to adjust axes as becomes necessary, also offers an obvious advantage. Having to discard a graph drawn by hand part way through because data moves outside the expected range can be an interesting learning experience, but may also be quite demoralising to some pupils.

Once students are familiar with data loggers they can be incorporated into genuine student enquiry tasks to offer learners an authentic experience of what it is like to do science (Davies, Sprague, & New, 2008). Data loggers can also be used in teacher demonstrations with great effect: such as using sensors to convert a pupil's movements in the classroom into distance-time or speed-time graphs. Other related applications include the use of digital cameras and microscopes that allow the teacher to share images with the whole class in new ways.

The computer as a teaching machine

The applications discussed so far relate to the teacher using the computer as an instrument or tool to support their teaching, in similar ways to other classroom equipment such as the OHP, or traditional laboratory apparatus such as Bunsen burners and microscopes. These applications make use of the speed and capacity of modern machines and their ability to interface with information sources such as the www and other devices such as temperature probes and cameras,

However, a more interesting aspect of ICT development is the possibility of making more use of the interactivity that can be built into computer software: that is in the area of teaching machines. The notion of a teaching machine is not new, and indeed programmed learning is an approach that does not rely on electronic computers (Bugelski, 1971).

It is possible to design programmed learning simply as a set of numbered cards. Each card can present some information, and a question with several possible answers. The student selects an answer. Depending upon which answer they chose, they are directed to a different card. (The same principle is used in some surveys: e.g. if you answered yes to question 7, please ignore questions 8-11 and move on to question 12.) A correct answer is taken to show understanding of one key point and the student is moved on to the next teaching point. If distractors (incorrect response options offered) are well designed they link to specific likely misunderstandings, and so the student making incorrect responses is directed to cards which respond to those specific points, before returning the student to the original card (or a parallel one covering the same core information).

The logic behind such materials is quite well motivated. Most school age pupils are not very skilled in learning from texts, so just reading a chapter in a book is not an effective way to learn. When teachers teach, they intersperse their informative statements with interrogative ones. They ask questions which test student understanding to inform decisions about what to say next: move on, repeat, go back over prerequisite material etc. Programmed learning materials are an attempt to build into a text the kind of interactivity that comes from working with a teacher or tutor. One set of well-designed programmed learning materials can potentially offer effective individualised routes through a topic for different students. The gifted and knowledgable move through quickly without inefficient and de-motivating wasting of time; the lower attaining student gets plenty of support and feedback, and several exposures to the key ideas on their path through the materials. When expressed like this, it might seem that such materials offer an advantage in a classroom situation: no matter how great the skills of a teacher, class teaching is always something of a compromise when trying to effectively and efficiently simultaneously teach the inevitably heterogeneous learners in any class. No matter what policies and procedures may be used to band or set students in a group, in practice every class is to some extent a 'mixed-ability' class: with each learner having their own strengths and are areas of prior knowledge.

However, it is also clear that this advantage of programmed learning materials can only be realised if the materials themselves are well designed. Indeed, in any substantive area of knowledge, programmed learning materials to meet the needs of a range of students would need extensive research and design, and are likely to become complicated and extensive. Certainly this would be the case if the materials are to come close to offering the level of interactivity available from a human teacher. The effective teacher calls upon three major knowledge domains: of the subject being taught, of the relevant subject-specific pedagogy, and of the pupils in a particular class. Computers, however, only 'know' what is programmed into them, and in most science teaching contexts it is currently unrealistic to think that it is possible to programme them to be the experts we expect teachers to be.

An important exception is in using computers to simulate virtual environments. Computers can be programmed with rules representing physical laws, and can quickly calculate – for example – how a projectile would move from certain initial conditions given particular physical laws and constant values. This is an example of a type of application where the processing power of the tool offers a perfect resource that can within its own terms be highly interactive as students experiment which changing initial conditions, or coefficients. Indeed working with such virtual micro worlds offers a real kind of experiential learning (Heuer & Blaschke, 2001; White, 1993).

In other science study contexts: learning about say the digestive system, the reactions of acids, or electromagnetic radiation, the computer-based learning is far from offering the interactivity available from a human teacher. However, despite the challenge of producing effective programmed learning materials, what is clear is that electronic computers – the epitome of the programmable machine – offer the ideal hardware on in which to run such materials. Whilst teaching machines that can replace classroom teachers may well still be some way off – if indeed such a notion was considered desirable – there is much potential for at least incorporating some of the basic features of programmed learning into software designed for educational use.

Challenges of conceptual learning in science

However, science teaching offers many challenges to the human teacher, and these need to be considered by those designing educational software that is intended for any degree of independent use (i.e. other than under direct supervision of the teacher). Indeed, the principles here are probably common to most 'academic' learning, but have been widely explored in the context of science learning, where it is known that students commonly come to class with their own 'versions' of science concepts at odds with the authorised versions presented in the curriculum (Duit, 2007). As children construct new knowledge on the basis of what they already understand and (think they) know (Ausubel, 2000; Taber, 2009a), these ideas are very significant for learning.

Indeed there has been a vast research effort that has explored the ideas about science topics that students bring to class; the nature of those ideas; and how best to shift student thinking towards the target knowledge set out in official curriculum documents (Taber, 2009a). This has shown that in virtually any science class – at any level, working on any topic – students are likely to hold 'alternative conceptions'. It is well recognised among science educators that many such conceptions have consequences for the intended learning (Driver & Erickson, 1983; Gilbert & Watts, 1983).

Studies suggest that the alternative ideas that students bring to class vary considerably along a range of dimensions: but that in some cases they may be strongly committed, tenacious, well-integrated into the student's frameworks of knowledge, and applied widely across contexts (Taber, 2009a). In some case such ideas have been found to be highly resistant to 'correction' during to teaching, and likely to reappear in student thinking in the medium term even when end-of-topic testing suggests short-term shifts towards the scientific models presented in the curriculum. A number of theoretical perspectives seem to usefully inform our understanding of the nature and development of at least some of these alternative ideas (Chi, 1992; diSessa, 1993; García Franco & Taber, 2006; Karmiloff-Smith, 1996), and research has suggested various strategies for responding to different classes of alternative conception (Bryce & MacMillan, 2005; Driver & Oldham, 1986; Treagust & Duit, 2008).

However, the literature is substantial, and even after some decades of research, it is still not possible to offer teachers clear and effective generalised guidelines for responding to students alternative conceptions in science: even if it is now clearer how the field needs to move forward (Taber, 2009a). What seems clear, is that whilst there are certainly some very common alternative ideas that will be found amongst learners in most classes (Taber, 1998; Watts & Zylbersztajn, 1981), many ideas student have are idiosyncratic (Taber, 1995) and need to be identified on an individual basis. So despite the undoubted value of research in informing teachers about the scope and nature of learners' idea in different topics, and different teaching approaches that can be employed, successful teachers need to coordinate this knowledge with their own specific understanding of particular classes and individual pupils. Teachers need to act as 'learning doctors' who diagnose student thinking at the individual level, and respond to them accordingly (Taber, 2001, 2002).

Developing computer-aided learning from a pedagogical model

This need to consider the individual ideas of particular students, and how these existing ideas will shape new learning, makes effective science teaching a highly interactive process. (And to the extent that children bring alternative conceptions to class in other curriculum subjects, much the same will apply to these subjects.)

This consideration adds complexity to any attempt to develop effective learning resources, whether they are textbooks, laboratory apparatus, or software. However, most learning resources bought by schools that are intended for use under close teacher supervision. Yet interactive software offers the promise of being something that can support learning with minimal teacher involvement: something learners can use in the library, or at home, freeing up the teacher to focus on other students, or allowing the teacher more time to spend on other topics or activities.

Such software needs to be a lot more than a textbook transferred to a computer, but ideally will provide at least the following features:

⍰ providing the learner with an overview of the area to be covered near the start;

⍰ providing navigation options to allow the learner to move about the material according to their own needs;

⍰ offering questions with feedback for the learner to check their understanding;

⍰ 'scaffolding' to allow learners to build up their understanding at their own pace;

Software which looks to respond to such requirements will be considered here as encompassing an instructional model.

Conceptual learning and scaffolding

As suggested earlier, a key feature of conceptual learning is that what is learnt depends upon what is already known: existing knowledge provides the conceptual frameworks through which new information is interpreted and understood. This is why alternative conceptions can be so significant, as they distort the teacher's meaning so that the learner understands material differently from intended. Learning is often seen as a process of knowledge 'construction' with existing understanding providing the foundations for new learning (Taber, 2009a).

Research in the cognitive sciences further shows that this 'construction' process is constrained by aspects of the available cognitive apparatus, as well as the conceptual resources available (Miller, 1968). Students learn science, or indeed other subjects, incrementally in terms of limited 'learning quanta' (Taber, 2005), even if there may be critical points where the accumulated material allows apparently sudden shifts in understanding (Gilbert & Watts, 1983). Designing instruction needs to consider both the 'building materials' students already have available, and the construction 'tools' they can use (Taber, 2008).

A key concept here is that of 'scaffolding', a notion developed out of the work of the psychologist Vygotsky by Jerome Bruner and his colleagues (Wood, 1988). Scaffolding is commonly described in terms of how teachers provide vicarious support for a student building up a new skill or conceptual framework whilst they are mastering new learning, and then gradually 'fade' that support as the student is able to take over. In terms of designing learning resources that can achieve this, the design has to provide 'scaffolding POLeS' (Provided Outlines Lending Support). However, often before students can take advantage of such devices, they need to first bring to mind and organise their existing relevant knowledge. These earlier types of supports – 'scaffolding PlaNKs', Platforms for New Knowledge – are also important in facilitating effective learning (Taber, 2002) – reflecting an important feature of so-called 'advance organisers' which can support meaningful learning (Kember, 1991).

In terms of educational software, the instructional design has to help the student recognise which prerequisite knowledge is relevant, and show them how it fits with new knowledge – as well as offer a way of structuring prior learning with new information to build up new understandings. To do this well is very demanding – after all when teachers scaffold learning in this way they are constantly interacting with learners and acquiring feedback that allows them to adapt their input.

To explore something of the demands of adopting these features into ICT based resources, one example of government commissioned educational software will be discussed in some detail.

The Epic design for computer-based learning resources

The example discussed here derives from some independent learning materials produced in the UK for the further education sector. The school leaving age in the UK is 16, although all school leavers are entitled to two further years of free education or training. Colleges that offer courses for those who have completed school, and which are (mostly) sub-university level, are considered to be 'further' education (FE) colleges. University level education, at Honours degree level or above, is labelled as 'higher' education (HE). FE colleges may offer a very eclectic range of courses to meet the needs of a wide variety of full-time, part-time and evening class students: those studying for entry to higher education, as well as basic skills (e.g. literacy and numeracy for adults), trade skills (motor vehicle, building trade etc), and professional qualifications (such as the professional accountancy and insurance examinations). Some FE colleges also teach parts of HE courses under the guidance of Universities, and they may also teach some students who are in the last few years of compulsory education (usually those who have been excluded from, or refused to attend, schools, and where although further school attendance is considered nonviable, the students are judged likely to respond to the more adult environment of a college). The FE sector also includes the so-called 'sixth form' colleges who specialise in teaching just 16-19 year olds, and often focus on courses leading to university entrance examinations.

The example of a computer-based learning resource considered here derives from teaching materials prepared to support students working at this level, i.e. working towards the 'A level' qualification. Students commonly study four A level subjects, and places for university courses are commonly awarded conditional upon certain minimal grades (with specific subjects required for many courses).

As part of a government funded initiative, an public sector organisation called the National Learning Network (NLN) commissioned the production of independent learning materials to support students working towards A level examinations in colleges in the FE sector. The contract for developing materials for physics (and several other subjects) was awarded to a company called Epic (Epic Group plc). Epic designed eight units of learning materials across a range of A level physics topics (Epic, 2004):

- rectilinear motion
- radioactivity
- electricity
- resistor
- circular motion and oscillations
- waves
- quantum phenomena

- fields and forces (two modules)

Within each unit there were several (normally two) different 'learning objects' (LO), i.e. specific foci for student learning (see Table 1).

Unit	Learning object (LO)
Rectilinear motion	Conservation of linear momentum Measuring the acceleration of free fall
Radioactivity	Properties of alpha, beta and gamma radiation Experimental determination of half-life
Electricity	Conductivity and resistivity Resistance change of a thermistor and a light-dependent resistor
Circular motion and oscillations	The motion of a simple pendulum Demonstration of forced, free and damped vibrations
Waves	Polarisation of transverse waves Stationary waves Diffraction of water waves and light waves
Quantum phenomena	Demonstration of the photoelectric effect Demonstration of the electron diffraction phenomenon
Fields and forces (1)	Newton's universal law of gravitational attraction The gravitational field strength at different distances from the Earth's surface Verification of Coulomb's law Electrical field lines in uniform fields
Fields and forces (2)	Principles of a cyclotron Principles of different radiation detectors

Table 1: Topics included in (UK) National Learning Network Level 3 Physics blended learning materials

The modules were drafted by 'subject matter experts' (experienced teachers of Physics at Advanced level), according to an outline 'template' designed by Epic and informed by their instructional model (detailed below). Materials were trialed with focus groups and in authentic teaching contexts before the materials were delivered to the NLN to be made available to colleges.

The materials were expected to be suitable for use in a range of modes. Of particular relevance here is their use as independent learning materials that could be accessed, in a library or resource area, without supervision by subject specialist staff. However, the materials were not intended to replace normal classroom based learning, and also had to be suitable for other modes, such as acting as taster or remedial materials, or being used with a class led by a subject specialist teacher.

The instructional model used in the Epic materials

The instructional model adopted for the NLN Physics materials involved a sequence of stages, each realised as one or more screens that the student would met in a sequence if they worked through the materials in the recommended order.

Each unit began with an introductory screen that was designed to engage the learner's interest and introduce the topic covered – i.e. an orientation phase. Next comes a screen concerning the aims of the unit, setting out what the student should expect to learn when completing the unit.

This is followed by a screen eliciting 'first thoughts' - where a student is asked a question to get them to think about their existing understanding of the topic area. (This screen could be considered to act as a scaffolding 'PlaNK' in the terminology introduced above.)

The next screen or two make a 'presentation' of the main ideas being explored in the unit. This usually involves some form of interactive animation, and was intended to be suitable for being used in 'demonstration' mode by a class teacher as well as being part of the sequence met during independent learning. For example, the student interacts with an animation to make changes in a circuit and observes the change in the reading on an ammeter; or the student moves different materials between a radioactive source and a detector, and observes the change in the rate at which events are detected. There then follow a number (c.5) of 'investigation' screens, which allow the learner to explore the key idea in more detail (and act as scaffolding PoLES in the terminology used above).

After working through the 'presentation' and 'investigation' sections offering the core knowledge, the learner is invited to apply their knowledge by answering an open question that tests understanding of the learning objectives built into the unit. A model answer is provided that the student can compare against his or her own response. This is followed by a 'summary' which highlights the key learning points, and then a 'check your understanding' section of three screens offering objective questions (where the student responses can be logged for a tutor).

The instructional model is illustrated in Table 2. The learning materials were intended for use in a virtual learning environment (VLE), and included features such as colour screens with illustrations, links to glossary entries, and audio versions of text (which were tested at the UK Royal National College for the Blind).

Section	Notes – how the screen(s) in the section fit into the overall design
Introduction	Designed to engage student. Links concepts of topic with some real-life application judged likely to be relevant to students (mostly 16-19 year olds).
Aims	Allows the student to see the scope of the work they will undertake, and what they are expected to achieve – helps act as an advance organiser which focuses the student on key issues/concepts
First thoughts	A question to elicit the student's existing thinking about the topic.
Presentation	Interactive demonstration of the key principle or idea. Offers a simulation of a hands-on investigation of the physics, and gives a visual impression of the key phenomenon.
Investigation	This section fills out the details around the key idea from the previous section.
Application	A question for the student to apply the ideas they have met in the unit, and a model answer to help them judge if they need to review any of the previous screens.
Summary	The ideas met in the unit are set out in a single summary screen to review learning.
Test items	A series of objective questions testing understanding of the ideas met in the unit.

Table 2: The instructional model used by Epic for the NLN Physics materials

A case study of the NLN Physics materials being used in independent study

Once the EPIC materials had been completed and prepared for trials, I asked several students studying physics at A level if they would work through a topic for me, so that I could get a feel for how well the instructional model supported independent student study.

Given the limited space here, I will briefly discuss how one student, who I will refer to by the assumed name of Adrian, got on with some of the materials. Adrian worked through two of the units, during separate sessions. On each occasion Adrian worked alone at a computer on trial versions of the software, observed by the present author.

Adrian was instructed to work in a 'think aloud' mode. 'Think aloud' or 'talk aloud' is a technique used by researchers investigating how people think when carrying out a task (Phang, 2009). The research participant is asked to vocalise their thoughts so that the investigator is able to follow the participant's reasoning.

As with all research techniques there are disadvantages (Branch, 2000). Firstly, the technique is clearly limited to the participant's conscious thinking: even an honest and full report does not give access to implicit thinking. This is not a trivial point, as we are not always aware of all the stages in our thinking, and sometimes the reasons we give for certain decisions may be (without our realising) after-the-event rationalisations of our sub-conscious decision making (Taber, 2008). Secondly, conscious thinking is not all verbal in nature. So for example, Einstein reported that much of his thinking about physics was in images (Miller, 1986): which would have to be re-represented by being described in words to be reported. The very act of 'translating' thinking to verbal form, and so unavoidably and inadvertently modifying it, is likely to change the course of that thinking compared with how the individual's thinking would have proceeded without this step. Thirdly, there is clearly a cognitive load on asking someone to report their thinking out loud: such an additional demand surely slows, even if it does not impede, the normal thinking processes. These demands are such that researchers who use talk-aloud regularly report that a small-but-significant minority of individuals prove unsuitable as participants in such research – being unable to both proceed with the task *and* provide a full running commentary at the same time.

Adrian was a sixth-former (i.e. in post-compulsory education), who was studying A level sciences including physics. He was in the second year of his two-year course. Adrian's sixth-form centre was part of a secondary school, but he was in the same age range and undertaking the same course as students studying in FE colleges for whom the materials were designed. (Diversity is a characteristic of the English education system, so 16-19 year olds studying 'A levels' may be in schools, specialised sixth form colleges, or general FE colleges.) Adrian was one of a number of students at his school who had volunteered to participate in a project to explore aspects of student thinking and learning about school science. The *Understanding Science Project* (Taber, 2009b) was based on sequences of interviews exploring student thinking across different science topics they met in schools.

Usually students are only allowed to enroll onto A level courses if they have performed well on the school leaving examinations (the General Certificate of Secondary Education). However, many students find Physics a difficult subject at this level, even when they previously coped well with school science. From my research sessions with him I considered Adrian to be capable and motivated student: genuinely interested in physics, but without demonstrating exceptional ability in the subject. Adrian was invited to try out some of the NLN materials, and he agreed, recognising that this could be a useful additional learning opportunity.

Adrian first worked through the learning object on *the motion of a simple pendulum*, and then a few weeks later the learning object on the *demonstration of the photoelectric effect*. On both occasions he worked in a quiet room at the University with only the author present. Adrian's school was only about a kilometre or so from the University's Faculty of Education, and as he lived very close to the Faculty it was decided to undertake the sessions there, away from potential distractions at school. Both sessions took place in rooms in the Science Education Centre in the Faculty: one in a teaching room, the other in the author's office. The sessions were held in Adrian's free time and did not require any withdrawal from his usual classes.

Here I will briefly discuss the LO on *the motion of a simple pendulum*, and consider how Adrian fared in interacting with the materials. To give a flavour of the procedure, I'll quote from the start of Adrian's think-aloud protocol (as recorded and transcribed by the author) as he start looking at the LO on *the motion of a simple pendulum*. The material underlined is material that Adrian read aloud from the text on the screen.

> "So it starts with erm, talking to you about history, erm it's got the pendulum has played an important role throughout history. It's then got four pictures, one of an old guy, an old painting, which when I put my erm cursor on it, it comes up with the history of pendulums, the next one, number 2, is erm, just waiting for it to come up, it's not going to let me, oh it's also the history of pendulums, so I'm guessing it works through the erm, like a chronological order. Start with the first one, number 1, the pendulum gave us accurate time keeping from 1657 when Christian Huygens invented the pendulum clock. 2, this is just giving me more history, different names of people, talking about seismographs, and then it goes into simple harmonic motion at the end. Erm. [At this point the author offered clarification on navigation through the screens] So - [pause, c.4s] it's putting the pendulum into the modern day erm environment of a TV programme. [Pause, c.7s] And its saying what the aims of this section of the computer programme will tell us. [Pause 6s] It's good the way which it's got links like [i.e. to the Glossary], so you can link to different words which you might not know the meaning of. …"

The Introduction to the LO gave, as Adrian readily recognised some historical background to the science behind the pendulum. As well as Huygens (the 'old guy'), it also presented information about Foucault's pendulum and the use of pendulums in seismographs, before explaining that "the pendulum has simple harmonic motion…" which was "a characteristic of many other oscillating systems and its theory can be applied to electronics and waves". As the quoted protocol above suggests, Adrian passed over this material quickly, apparently considering it as little more than a preamble.

The materials then offered a context for thinking about the use of pendulums: a television game show where "the set is designed with a large pendulum which swings across the studio. The contestants will have to answer the questions correctly while the pendulum is swinging over their half of the studio". The student using the software is told that "you will advise the producer of the show on how he can use the properties of the pendulum to improve the show's format". The use of such contexts is intended to engage students by showing how the science is relevant to contexts likely to be of interest, and Adrian seemed to recognise this common ploy ("it's putting the pendulum into the modern day erm environment").

The 'first thoughts' segment of the LO is intended to elicit the student's prior learning about a topic, and to focus their thinking upon important features of the phenomenon. For this LO this comprised of a passage where the student had to respond by selecting the right response at a number of points where several words were offered. Adrian was quite familiar with this kind of task and proceeded:

> "When a pendulum swings, it travels fastest as it goes past a central point, which means it's kinetic energy is and it's giving you a list I think, oh yeah, constant, maximum, minimum, zero, so I think it's jut trying to find out what sort of things you know. Erm – I'm trying to remember what the answer to the question is, er, as it, when it's at its further point away, it hasn't got any potential energy, maximum potential energy, when it's let go, kinetic energy would be at a maximum as it goes through. As the pendulum swings away from the central position the magnitude of its displacement so I've just thought what displacement means, it means distance, erm, As it swings away from the central position the displacement *increases*. Erm, displacement's highlighted, I don't know what that means, I'm sure I could find out. I'll try that. [Adrian refers to glossary] … Erm, question continues, kinetic energy is – *decreasing*. Potential energy

> is – *increasing*. The something of a pendulum, is the time taken, the *period* of a pendulum. The maximum displacement of the pendulum from the central position is the - *amplitude*. Oh, something happened there. I pressed back by accident. Oh.

Adrian managed to work through the items, and to refer to the glossary to check the meaning of a term, only hitting difficulty when he then clicked in the wrong place after selecting his answers. He then corrected his mistake and proceeded to the next screen, which offered the model answer.

Ideally in a think-aloud study, the researcher sets up the participant with the task, and then retires to observe (perhaps often being out of sight of the participant monitoring remotely by closed-circuit television). However, I soon became aware that Adrian was tending to pass over or miss aspects of the learning materials, and that some interjections and prompts seemed appropriate.

The next part of the LO concerned the 'Presentation' where an animation allowed the student to simulate changing physical characteristics of a pendulum and find the effect. So, for example, changing the length of a pendulum alters its period; but changing the mass of its bob does not (although it does influence how quickly the oscillations are dampened and the swinging stops); and – to a reasonable approximation – nor does the initial displacement of the bob. This is why pendulums can be used in clocks – as highlighted in the introductory screen – as the period remains unchanged as the pendulum dissipates energy and the amplitude of the swing decreases. In the context used for the LO the student is told that "in order to advise the producer of the TV show, you will need to find out more about the format of the show and the set. This animation shows how the show is affected by using three different lengths of pendulum." The instructions read "Press start to see how the pendulum's length affects the time the contestants have to answer the question".

> Adrian: [Truncated reading] Press start to see how the pendulum effects, length effects time.
>
> Keith: Did you get any feedback on what you just did?
>
> Adrian: No, I don't think so. Oh. Okay so you've gotta - It's presentation now. Small pendulum. People are talking. I'm not entirely sure what it's showing me. Oh the effect that length of pendulum has. Okay so it's flashing up equations at me. However, oh, - I'm not sure, they're not linking the equations to – anything.
>
> Keith: So what do you think that's meant to demonstrate then?, that bit?
>
> Adrian: The equation's T, square root of one over g, I think, oh, 2π square root 1/g, so it's talking about the time period, but it doesn't – effects the time, the contestants have to answer the - . It's showing that, erm, the longer the pendulum, the longer the time period, I think. However, that's not very clear.
>
> Keith: Right, so is that what the animation does? What does the animation do?
>
> Adrian: Yeah. It says "Press start to see how the pendulum's length effects the time the contestants have to answer the question below", there is no question below, but, - so a medium pendulum, she gets it just as it goes past her, long pendulum, - she gets it well before it gets to her, so it's showing that it takes longer for a longer pendulum to swing, than a short pendulum.

Space here does not allow a detailed account of Adrian's progress through the LO, but these extracts from the protocol offer a fair impression of his engagement with the materials. Adrian was interested in the materials and seemed keen to work his way through: but he did not always seem to appreciate the intended interactivity of the materials without prompting by the 'observer'.

So Adrian was next asked to undertake a calculation:

> I think there was a question on the last bit; I must have just missed that. [Going back to check:] Okay what energy's involved. The pendulum will have blob [sic, bob] with a mass of 5kg. Just before the show starts the pendulum will be pulled to one side of the studio, lifting the blob a vertical distance of 1.2 m. The pendulum's gravitational potential energy will be converted energy as it swings. Click on each item to find out more. [1] How much gravitational [potential] energy does the pendulum have as it starts to swing? [2] So as I was reading through that I was thinking sort of what

> formulas do I know, erm, relating mass to erm energy, and distance to energy. [3] How much gravitational potential energy does the pendulum have as it starts to swing? [4] Ignoring the effects of friction and air resistance the gain in gravitational potential energy's mgΔh so in this case it is 5kg times 9.8 which is the gravitational field strength constant, or, yeah, times by 1.2m roughly 60. [5] The next question is what is the maximum kinetic energy of a [sic, the] pendulum?"

In this extract Adrian [1] reads out a question and [2] then correctly realises that he needs to identify the appropriate formula needed to undertake the calculation. However, instead of doing this he [3] re-reads the questions, then [4] reveals and reads out the model answer, before then without any further reflection [5] moving on to the next question.

Clearly in designing material of this kind, the intention is to get the student thinking, so that they are actively processing the ideas, and *then* offer them feedback on their answers. Adrian however showed no compunction is completely short-circuiting that process. At this point, I intervened to explore why Adrian had not made any attempt to work out the answer before looking at the answer:

> Keith: What if you think about [the questions] before you press the buttons, is that possible?
>
> Adrian : Yeah, that's what it's asking.
>
> Keith: Or is that something you would tend not to do, because – you know – there's a button that gives you the answer?
>
> Adrian: [Laughing] I guess you might think about it, but if you're using this as an initial learning aid, you wouldn't have a clue where to start, er, erm. It doesn't give you any hint where to start. Like I could understand if it gave you the formula and then said work it out, or erm, these things, these specific things erm will give you this or something if you use them in a certain way, but it's just asking you a question which, unless you've done work on, erm, on that topic before, you probably wouldn't be able to answer.
>
> Keith: I see, what was the first one, what did the first one say?
>
> Adrian: The first question was "how much gravitational potential energy does the pendulum have, at the start of the swing?"

> Keith: So what would you need to know to answer that?
>
> Adrian: You'd need to know the relationship between kinetic energy and potential energy, how if you've got maximum potential energy in a pendulum there's no kinetic energy because it's at its highest point. You'd need to know an energy formula to work our gravitational potential energy. Erm.

Adrian suggests two components of prerequisite knowledge here, but actually only the latter is needed. (Even if it was not clear to a student that the pendulum had no kinetic energy at the highest point, this information was not needed to calculate the potential energy.) The formula for gravitational potential energy was something Adrian should have known, and would likely have used at various points on his course.

> Keith: Would you know that already?
>
> Adrian: Not if you were using this for the first time, or if you'd had no other contact with, erm, if I'd just walked in first physics lesson on pendulums and, erm, circular motion and simple harmonic motion and everything, erm, then you might not know it.
>
> Keith: So if the teacher said we're doing a new topic and this is about pendulums, go away and look at this software, [yeah] then you wouldn't think 'I know how to answer that question'?
>
> Adrian: No, if you spent a lesson going through pendulums, and the effect pulling further away has on the energies, which would get you thinking about, well, do I know the formula for potential energy at a certain height or something?
>
> Keith: Do you know that?
>
> Adrian: I probably would have known it from like GCSE [secondary school work].
>
> Keith: Not from pendulum work necessarily?
>
> Adrian: No, however you've got to be able to like relate it, and that's, although you may know the formulas [sic] it's being able to think 'right, that's a formula I know', cause like in circles, there's different formulas for acceleration, acceleration's v-r-squared over something, or something like that. … whereas in an, just in a normal erm, like pulling something along a surface, f = m a, acceleration equals force over mass, and so you've got to be able to sort of see the problem, almost…

The calculation that Adrian was being asked to undertake required the application of a relationship that was considered by the software designers to have been prerequisite knowledge for the topic. It was expected that most students working on these materials would be able to access and apply this knowledge in the new context. At the end of the exchange above, Adrian acknowledges that he should have been able to tackle the question - as he had previously met the formula and identifying which formulae apply to different contexts was a skill expected in physics.

Presumably if a physics teacher introducing the topic of pendulums had asked Adrian the same question, he would have assumed that the teacher had good reason to expect him to be able to respond to the question. Yet in the context of working with the software, Adrian simply assumed he would not know the answer without completing the work – even though it was presented early in the teaching sequence. Adrian did not seem to consider that the materials would have been carefully designed following an instructional model.

The session continued in this fashion, with Adrian working through the rest of the LO, but with regular prompts and questions form the author. The process took just over an hour.

When Adrian had completed the LO I asked him about his overall impression of working through the software. At this point, having completed the full sequence, Adrian now seemed to recognise how the LO had been designed to follow an instructional model:

> "It works through a process that you will have worked through in class. Like that's the same type of process I worked through when I did pendulums. … It's er, it's similar in that you get given an idea of what it's going to be about in the beginning in the aims, and so it's

> sort of erm gets you thinking about possible things that can be linked, erm and then it starts off with things which you will probably, well should already know, like the initial energy equations, erm and it sort of tells you that they are related to this topic, it then gets more involved with a new equation that you probably haven't seen before, time period, and the effect the time period has on, or how you work out time period from graphs and stuff. Erm, what does it do then? Oh yeah, and then it uses that equation, so it makes sure you can use it, erm it didn't just throw you straight in with a four-part question, starting with energy, talking about time periods, simple harmonic motion getting completely confused, it gave you a simple question. Erm, It then, what did it do then? Oh yeah, it then asked you the three questions, the first one was using the equation you had just learnt, again slightly more complex, because it was a different idea. The next one was erm using almost everything you had done in this little section, it's talking about energy and the equation. And the last one was general ideas that you need to be able to remember when you are answering questions, so the true and false. I think the way in which it worked through was sort of building everything up, so that when you go into an exam, you think about the right things."

Adrian had found the experience useful in reviewing the topic area, although he claimed not to find the use of a familiar context (the television game show) especially engaging,

> "I don't think it would have bothered me if they had [just] given you a diagram of a pendulum swinging. I don't think that would have made any difference to me, the game show. I guess they're trying to make it more related to things, but I mean I don't think it makes a huge difference, once you get to like upper sixth physics, you know what I mean? … I mean maybe like the year 7, 8, 9s [i.e. 11-14 year olds], then yeah, they probably don't want to be doing physics half of them, and so like linking it to something else, taking their mind off the actual physics is a good idea"

It is important not to read too much significance into a single case of a student using learning resources, especially in a format that was unfamiliar. However, although Adrian found the materials useful, it seemed he would readily have ignored much of the potential of the interactivity of the resource, and simply skipped through to where he was being given information, had be not been guided by the author.

A few weeks later Adrian undertook a second LO (*demonstration of the photoelectric effect*), and at the end of that session he was very positive about the resource: "I thought that was really good actually…they sort of talk you through, building it up, … and I felt I understood it because of they way they built it up, and they told you specifically there were three things that, three factors, things like that". When asked if there was anything about this LO that he did not find helpful, Adrian suggested "no, I think it was all necessary, like, to make sure you understood it. It was all necessary stuff".

The overall message from this particular case is that the NLN Physics materials were based around an instruction design which had strong potential to engage students in the learning process, but that students may be tempted to bypass the built-in interactivity – especially if they did not expect (perhaps based on their experience of using other educational software) that the LO would be carefully designed as a learning resource.

An example of the EPIC NLN Physics materials being used in supervised study

The second use of the NLN materials discussed here was with a group that would not be considered part of the intended target audience for the materials. These were secondary level students, 14-15 year old pupils, attending an enrichment programme called ASCEND. ASCEND, *Able Scientists Collectively Exploring New Demands*, was an after-school programme designed to meet the needs of the most able in secondary science classes (Taber & Riga, 2006). ASCEND was supported by funding from an Educational Charity, the Gatsby Science Enhancement Programme, and was based at the Faculty of Education in Cambridge, working with Comprehensive Schools in the

City of Cambridge (Taber, 2007a). The four partner schools identified students in Y10 (14-15 year olds) who they felt would benefit from being challenged in science, and were interested enough in the subject to want to attend after school sessions at the University. This was seen as one way to support schools in meeting their expectations under government 'Gifted and Talented' policies (Taber & Riga, 2007). However, as the notion of giftedness in science is a disputed concept, and the approaches adopted by schools to identifying students for schools 'gifted' registers can seldom be considered rigorous or sophisticated (Taber, 2007b), there was no strict requirement that all delegates (attending pupils) should be formally included on the schools' list of students gifted in science. Nonetheless, the 30 or so delegates who attended sessions were certainly among the more able in their age group, and some would certainly be considered gifted by most criteria.

ASCEND sessions were each organised around different themes, most of which were linked to the nature of science (demarcation, explanations in science, philosophies and scientific method, scientific laws, models). However for one session students were given the option of working with the NLN physics materials, and most of the delegates chose to take up this option.

The NLN materials were designed for older students who had successfully completed their school level science, so it was clearly a risk to invite younger students likely to be lacking some of the assumed prerequisite knowledge to use the materials to try out the programmes. Five of the LO which considered more accessible were identified, and the students directed to select one of these:

- electricity – conductivity and resistivity

- fields and forces – the gravitational field strength at different distances from the Earth’s surface
- quantum phenomena – demonstration of the photoelectric effect
- radioactivity – properties of alpha, beta and gamma radiation
- waves – diffraction of water waves and light waves

The delegates were allowed to work in pairs if they wished, and had access to support from the project’s graduate assistants. These were Faculty students whom were either preparing for science teaching on the Post-Graduate Certificate in Education, or who were undertaking research degrees in science education. The graduate assistants’ general brief for the project was to primarily act as observers, and not to seek to teach the delegates on the set tasks unless they specifically requested help. However, they were available to offer support whenever the delegates wanted to refer to them.

It was not expected that the delegates would be able to master all the ideas in one of the LO in the time available (about 90 minutes), but it was hoped that as able and motivated science students they would find the materials engaging and a useful taster for the types of material they would study if they selected physics as an A level subject after completing school science.

After each ASCEND session, the graduate assistants were asked to email in their observations of the session. The following comments are extracted from their reports

> "Around the room there were many absorbed expressions and good, interested questions were being asked. The program definitely encouraged thought and focus. …The autonomy to find out and progress through for themselves in an accessible and presentable format gives the [gifted students] a huge selection of information and good opportunity to access it."
>
> "The atmosphere in the computer lab was amazing"
>
> "Everybody worked through the topics that you specified. So obviously they were captured by it, with no email-checking or laser-game playing ... I think the explanations were quite clear (certainly clear enough for those year 10s) and I only had a couple of really basic questions like, which symbol is gamma, and which is lambda."
>
> "All students were engaged with the program, and quite happy to work through it unaided … they were able to navigate their way through it without any difficulty. I was surprised at how keen they were to get on with it. I noticed some did stop and think about what they were doing and talked to each other about it. Some students even questioned the validity of the physics they were presented with!"
>
> " I was impressed by their motivation, on the whole it was sustained for the full 90 mins."

The graduates also noted that they did not feel the software could have been used by these learners without some teacher support; that there was some skipping through sections (reflecting the experience with Adrian, above); that the mathematical demands were too high for some of the Y10 students; and that they suspected that some of the understanding was at a relatively superficial level. However, these points are to be expected given the apparent mismatch in maturity and knowledge between these children and the target audience for the materials.

The overall impression though was very much that the design Epic had adopted for the NLN materials had enabled these able younger learners to access and work with areas of physics beyond their school curriculum, and to do so with interest, enjoyment and enthusiasm.

Conclusion

This chapter has considered the design of educational software used to support learning in science. The chapter began with a consideration of the nature of ICT used in classrooms, and potential issues about the development, adoption and effective use of such technology in classrooms. It was suggested that there are barriers to effective use of ICT in teaching: including potential mismatch between what resources may offer, and what teachers feel can support them in meeting their educational aims and objectives. However it was also pointed out that, for example, in science ICT has strengths that offer potential to considerably enhance teaching and learning.

The main focus of the chapter has been on the use of ICT to provide learning resources for students (especially hose that can be used with limited or no teacher supervision), and in particular on the need for these to be carefully designed in terms of pedagogy as well as subject knowledge. This is particularly so in science, in view of what is known about the challenges teachers face in encouraging conceptual change among students. Effective teachers work in a highly interactive mode in their classrooms, making on-line decisions based upon their subject knowledge, their pedagogical subject knowledge, their personal knowledge of the class and individual students; and taking into account contextual issues (how the pupils are today: irritable, tired, enthusiastic etc). Designing learning materials that could compete with teachers is currently a very unrealistic task.

However the chapter considered in some detail one example of learning materials written by experience subject specialist teachers to a design template based on an instructional model. The Epic design template used for the UK's NLN Level 3 physics materials (commissioned to support teaching and learning in the FE sector), adopts many features used by teachers in planning their own work.

A case study of a Level 3 (A level) physics student using the materials for the first time was discussed in some detail. This raised some doubts about whether students using materials such as this in an inpendent learning mode would fully benefit from the design features. Despite this, the student clearly found the materials very useful, and with some 'teacher' input (probes and questions from the author) worked through much of the thinking process anticipated by the materials designers.

Further, the use of the NLN materials with younger students who had not yet completed their basis school science suggested that the design of the materials supported engagement and learning even with learners who had not yet completed the previous stage of their education - showing that the intention that the materials could offer a useful 'taster' for students who may be interested in choosing physics at college levels (Epic, 2004) was effectively met. The students in this case were known (by virtue of being involved in the ASCEND project) to score highly on both interest in science, and science attainment – however, both these qualities would be expected of students admitted to A level physics courses in FE. More significantly, the successful engagement of these younger students with the learning materials took place in a context where they could work together and had teacher input available on-call. One of the features of this session noted by one of the graduate assistants was the level of conversation about the materials that was stimulated between students.

What this seems to suggest is that the challenge of producing learning resources that can be used for effective inpendent student study should not be underestimated. Students will 'miss' features, or deliberately 'skip' steps that look difficult, or where they know the answer is available at the touch of a button. However, as we saw with Adrian, learners may also quickly come to appreciate the design of materials that have pedagogic features carefully built into them, so some of this tendency to miss parts of the intended process could be overcome with strong induction into the use of resources. However, both in the case of Adrian, and in the ASCEND project, it was clear that the interactivity available in the software was more fully employed in the context of the learner having another human to refer to: whether a teacher or a peer.

The Epic designed UK NLN physics materials encompass an effective design, based upon sound pedagogic considerations, and clearly show that the design of educational software can be informed both by good subject knowledge and good educational thinking. The present work does however suggest that even well designed learning resources are likely to be most effectively used by dyads of pupils, or at least when students have some level of teacher supervision.

Perhaps in the future software development will progress further, or students' educational experiences will change (as they increasingly get used to working with ICT in school regularly from a young age), so that computer-based resources for fully independent learning start to offer a comparable experience to being taught by a good teacher. However the present state of the art seems should be reassuring for teachers: there are now some very well designed tools to support them in their work, but they are not yet in any real danger of being replaced by the ICT itself.

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