

## **Pedagogical Approaches for Technology-Integrated Science Teaching**

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### **Abstract**

The two separate projects described have examined how teachers exploit computer-based technologies in supporting learning of science at secondary level. This paper examines how pedagogical approaches associated with these technological tools are adapted to both the cognitive and structuring resources available in the classroom setting. Four teachers participated in the first study, undertaken as part of the InterActive Education project in Bristol; all of them used multimedia simulations in their lessons. The second study presented was part of the wider SET-IT project in Cambridge; 11 teachers in eight schools were observed using multimedia simulations, data logging tools and interactive whiteboards. Teachers were interviewed in all cases to elicit their pedagogical thinking about their classroom use of ICT.

The findings suggest that teachers are moving away from only using ‘real’ experiments in their practice. They are exploring the use of technologies to encourage students to engage in “What If” explorations where the outcomes of ‘virtual’ experiments can be immediately accessed, for example through using a simulation. However, this type of activity can serve just as a mechanism for revealing – and indeed reinforcing – students’ informal conceptions if cognitive conflict is not generated or remains unresolved. The teachers in our studies used simulations, data logging, projected animations and other dynamic digital resources as tools to encourage and support prediction and to demonstrate scientific concepts and physical processes – thereby ‘bridging the gap’ between scientific and informal knowledge. They also integrated technology carefully with other practical activities so as to support stepwise knowledge building, consolidation and application.

Research of this kind has design implications for both curriculum-related activities and emerging computer-based learning technologies, in terms of helping us to understand how teachers capitalise

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upon the technology available in supporting students to construct links between scientific theory and empirical evidence.

**Keywords:** *Applications in subject areas; Pedagogical issues; Secondary education; Simulations; Teaching/learning strategies*

## **1.0 Introduction**

The two research studies reported here were presented together in a symposium which brought together independent teams from different institutions, and a discussant (Whitelock), who shared a concern with the evolving development of pedagogical thinking about integrating the use of technology into science teaching and learning. The shared questions that underpinned our work were:

How can teachers support students in using interactive technologies to access the ‘theory-world’ of science (Whitelock & Jelfs, 2004)? How is the pedagogy associated with this goal shaped by the cognitive resources that learners bring to bear (Schoenfeld, 1985) and by the structuring resources available in the specific educational setting (Lave, 1988)?

We draw upon the well-established literature of students’ prior conceptions – intuitive beliefs about natural phenomena derived from experience (Driver et al., 1985; Osborne, 1985) – which highlights the importance of structuring activities so as to make implicit reasoning explicit. Teacher intervention and guidance which elicits, discusses, challenges and builds upon learners’ own ideas, describes and interprets shared experience and highlights continuities (Mercer, 1995) along with differences between scientific conventions and informal ideas (Scott & Jewitt, 2003), is considered critical for students’ ultimate (social) construction of more abstract, general and explanatory knowledge frameworks (Driver et al., 1994). The complex and counter-intuitive nature of scientific concepts and processes mean that opportunities for discussion, reasoning, interpretation and reflection are very important for knowledge building. Introducing technological tools and resources which students can use interactively potentially offers further opportunities for expressing, evaluating and revising their developing ideas as they visualise the consequences of their own reasoning.

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In the studies reported here, three different technologies were used as tools to support science learning: multimedia simulation, data logging and interactive whiteboards (IWBs). Simulation offers idealised, dynamic and visual representations of physical phenomena and experiments which would be dangerous, costly or otherwise not feasible in a school laboratory. It releases students from laborious manual processes, both expediting work production and enabling teachers and learners to focus on overarching or salient issues without distraction (Osborne & Hennessy, 2003). Simulation use is considered to support science learning through encouraging students to pose and investigate exploratory (“What If...”) questions and yielding less ‘messy’ data (e.g. Baggott & Nichol, 1998). Data logging automates the recording and handling of experimental data through use of sensing equipment which offers immediate feedback and alleviates laborious data collection and graph production (e.g. Newton & Rogers, 2001). Immediate feedback from the dynamic graph display enables actions to be monitored and adjusted; however, demonstration remains the common mode of use. IWBs are a more generic tool which offer spontaneous access for a whole class to a wide range of projected Web-based and multimedia resources whose projection, manipulation and annotation features serve to facilitate visualisation of abstract knowledge (Becta, 2003a; Smith, 2003). IWBs have become widespread in secondary schools only recently. The embryonic research literature indicates that while student manipulation potentially offers opportunities for collective knowledge building, use is actually reinforcing a teacher-centred didactic pedagogy lacking in adjustment to individuals’ responses (e.g. Coghill, 2003).

Our work builds on the previous wave of research into use of ICT in science which has focused on the design of pedagogical principles for applications such as simulations and animations. These include:

- Predict, observe and explain (Champagne et al., 1980; Hennessy et al., 1995; Whitelock et al, 1995)
- Tell, explore and check (Whitelock et al., 1995)
- Analyse, explore, plan, implement, verify (Pol, Harskamp & Suhre, 2005)

Underlying all of these principles (which have also been advocated by software developers and implemented in their systems) is the notion that direct manipulation of abstract representations of concrete objects and phenomena can assist students in exploring and testing out their ideas about the natural world in comparison with the theoretical world of science (Hennessy & O’Shea, 1993).

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Much of this work, however, has been carried out in laboratory settings; the two projects described below have extended it to secondary school students' use in real world educational settings and examined how the constraints operating are shaping pedagogical approaches.

### **2.0 Pedagogic strategies for exploring the benefits of multimedia simulation to support science learning: Findings from the InterActive Education Project**

This project investigated teachers' use of simulations in the classroom. It was set up to probe how science lessons could be designed which incorporated relevant and interactive software into a sound pedagogical strategy for a number of science topics. The study draws on the concerns documented in the recent literature about the effective use of simulations for science teaching.

Baggott la Velle, McFarlane and Brawn (2003) emphasise the fact that using simulations effectively in science teaching is not as straightforward as it first appears. They describe the complex and interrelated processes of subject, pedagogical, technological, curricular and contextual knowledge transformation that a science teacher needs to undergo in order to teach successfully through simulation software. Wellington (2000) too points out a number of actual dangers inherent in simulation use in science: they are idealised versions of reality built upon invisible, unquestionable, often simplified models of a scientific process that give students the impression that every variable is easily controlled.

Newton and Rogers (2003) describe simulations and other ICT tools as adding value to science lessons in two ways: the first through intrinsic properties of the software; and the second through potential student learning benefits such as clearer understanding. It is the planning decisions made by the teacher about how to use the software that are critical to securing these learning benefits. This section of the paper reports on the reflections of four experienced science teachers on their planning for the use of simulation software and what they see as the intrinsic properties of simulations that enhance learning.

## **2.1 Methods**

The four teachers (from different schools) were participants in the science strand of the InterActive Education Project (<http://www.interactiveeducation.ac.uk/>) undertaken over the past three years by the Graduate School of Education at the University of Bristol as part of the ESRC-funded Teaching and Learning Research Programme. In this project, over 50 teachers of a range of secondary school subjects, identified by their senior managers as being suitable candidates for the initiative, were partnered with University teacher trainers in the same subject and asked to create new lesson designs termed Subject Design Initiatives (SDIs) for using ICT in their teaching. They were then monitored throughout the design, implementation and review of these lessons. Each lesson was videoed in its entirety and followed up by a semi-structured post-project interview lasting between 1 hour and 1 hour 45 minutes. The broad aims of the interview schedule were to investigate:

- Teachers' perceptions of the relative successes, problems and challenges of working with ICT
- Change over the period of the project in teachers' approach to incorporating the use of ICT in their practice and how this relates to student learning
- Change over time in teachers' views about ICT in teaching and learning
- Teachers' views about the processes they experienced during the project (e.g. SDI teams, partnership).

## **2.2 Findings**

Simulations were used in hands-on mode by the students in all cases. Teachers considered that offering students a degree of control over their own learning can provide challenge, motivation and engagement for a wide range of student groups. This view resonated with Wishart's (1990) observations of students using both games and simulations. Teacher interviews corroborated the key affordances identified in the literature, in particular linking learning with the power of animated visual representation, and lessons were designed to capitalise on this. For example when Teacher D chose to use a Web-based interactive simulation of a voltaic cell the justification was as follows:

It's all right saying the electrons are there, but it's another thing to actually *see* them doing what they should be doing, and sort of having the effect that they should be having.

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Simulation was also employed in order to release students from laborious (and often confusing) manual processes. Teacher A used a simulation package ('Crocodile Physics') to teach electric circuits and found it useful because it allowed the students to interact directly with the concepts being modelled without the interference to their thinking that too often arises from the poor connections found in electrical circuits constructed in school.

A shift in the teacher's role in the classroom was also described, for example by Teacher J who set out to compare teaching through simulation software (see Figure 1) with a standard school laboratory practical investigating the effect of temperature on enzyme activity with Year 10 (fifteen year-olds)<sup>1</sup>. He reported that conducting the experiment in real time means that practical issues often supersede the teacher's 'intellectual input', whereas once the simulation was running he spent less time helping children to understand what the task was and more time 'discussing the learning points that the simulation was there to demonstrate'. He was concerned though about the predictability of the dataset that is programmed into the simulation and pleased that a number of his more able students realised this limitation of computer models:

Of set 1 probably about 4 or 5 came up and said 'This is no good as coursework because we can't vary anything. We're varying things [temperatures], but we're all coming up with the same results.' Brilliant. They'd actually seen the top end limitation of the computer simulation... And in a way that's more useful to understand – that computers are limited.

<Figure 1 about here>

J's experience highlighted the importance of the relationship between the students' ability and the way that the simulation software supported their learning; on reflection, he realised that he needed different teaching strategies for using the simulation with his two student groups. With the less able group the power of the simulation to increase their scope of experience through visual representation was paramount. Similarly it was allowing them to repeat experiments as often as necessary, which could not be done practically: "You can generate far more data, and see the whole

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<sup>1</sup> Year 10 students in the UK are in the first year of their General Certificate of Secondary Education (GCSE) double award science course.

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curve rather than four points on it.” However, with the more able group, he would need to plan a lesson that addressed the premises on which the model underlying the simulation was based.

Teacher **B** took this latter point further. He was teaching electrical circuits to a group of able students, also in Year 10. After introducing the theory he then used a CD-ROM called ‘Furry Elephants’ (see Figure 2) with the group in order to clarify the underlying principles of energy carrying charged particles before they went on to plan an investigation into the resistance of wire as individuals.

<Figure 2 about here>

Unfortunately, some of the graphics used in this simulation indicating energy being dissipated at specific components conflicted with the conceptual understanding already developed by some of the more able learners in the group that energy is dissipated throughout a circuit. **B** used this discovery of the need to review the models used in many simulations carefully in developing a second SDI for older students. This second SDI focused on Year 12 (16-17 years) pre-university physics<sup>2</sup> students using the Internet to research and review examples of photoelectric effect simulations.

Therefore, both of **B**’s SDIs included discussion around the fact that the students’ understanding of the topic was actually in conflict with what was being represented in the simulation. **B** was particularly pleased with the students’ responses to the second SDI, he concluded that this was an effective way of using the resources on the Web, because it could circumvent the problems of incorrect science in the simplified models used:

They have to be critical. They’re being more active and proactive in their learning, rather than just reacting to what they’re seeing in front of them and automatically grabbing it off the Web because it looks pretty. They’re being critical. And teaching critical thinking has got to be a good way forward.

Teacher **B** hit upon a method of planning for the use of simulations in science that might go some way toward allaying Wellington’s (2000) concerns about them being idealised and simplified

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<sup>2</sup> Doing the UK Advanced Subsidiary (AS) examination

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models of reality. By immediately acknowledging that the models on the Internet were not all perfect and asking able or older students to review them in the light of how effective they were at illustrating the photoelectric effect, he enabled students to reflect on and review their own understanding, reinforcing and consolidating the concepts being taught. B reported that:

Following the SDI the Year 12 students displayed a greater confidence in their use of scientific terminology associated with the photoelectric effect and had gained a deeper understanding of the concepts underpinning this.

He considered that as an activity

It worked very well and I think the fact that they were able to do it in their own time was a better utilisation of time and didn't have the associated problems with computers [in school].

The teacher also asked the students to compare the explanations given to them from the Web, from himself and also from the textbook. In this way they could start to explore and check the scientific explanations from these various sources. In effect they were engaging in meaning-making activities which prompted them to contrast their own ideas with the scientific models. The role of the teacher here is to promote cognitive change and he is employing a strategy advocated by Doise & Mugny (1984) that states that group-generated conflict stimulates the joint construction of a more advanced concept. This strategy has also proved effective for teaching science concepts to primary school children (Howe, Tolmie & Anderson, 1991).

### **2.3 Conclusions and Recommendations**

These science teachers moved on from their original perspective that simulation was an impoverished version of practical work. Their reflections on the intrinsic properties of simulation software confirmed the key areas of its potential to transform teaching and learning in science lessons as summarised above and by Osborne and Hennessy (2003). The teachers concluded that the following pedagogical strategies exploited these intrinsic properties and led to effective teaching and learning:



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- Allowing students to manipulate simulations themselves and including time for the students' own “What If...” scenarios in planning for use of simulations in the classroom.
- Pointing out the imperfections in the idealised models used in simulations. Asking students to research them allows them to clarify their own understanding, reconciling it with the concepts being taught.
- Employing different teaching strategies for using the simulation with less and more able students. With a less able group, planning around the visual representation is key but with a more able group, the teacher needs to address the premises on which the underlying model is based.

Understanding the strategies that teachers employ to promote effective teaching with new technologies was also the subject of an investigation by the Cambridge University team and this is described below.

### **3.0 Situated expertise in technology-integrated science teaching: mediating learning and adapting to constraints**

The work reported here was part of a wider research project (SET-IT)<sup>3</sup> which aimed to elicit and document the strategies evolving for productively integrating use of technology into classroom practices in secondary-school mathematics and science. The research literature shows that experts have acquired intuitive specialist ‘knowledge in action’ which is interwoven with the context in which activity takes place (Brown et al., 1989). Expertise is finely tuned to the teaching and learning setting and it incorporates the capacity to respond flexibly to the uncertainty and contingency which are normal in real life situations (Wynne, 1991). The study described here investigated how the pedagogic expertise of science teachers is adapted to the constraints imposed and the affordances offered when educational technologies are introduced. The specific focus of our study was on whether and how teachers are successfully mediating students’ learning of

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<sup>3</sup> The SET-IT project (“Eliciting situated expertise in ICT-integrated mathematics and science teaching”) ran from 2002-04 and was funded by ESRC grant R000239823.

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scientific concepts and processes using three common technologies – multimedia simulation, data logging and IWBs. Our goals were to examine practitioners' expertise in using these powerful tools across a range of classroom settings so as to understand the nature of the tuning process, to elicit the rationale behind different kinds of teacher support and intervention, and to explore opportunities for student experimentation and participation.

### 3.1 Method

Exemplary cases were carefully selected through a multi-stage sampling process. Firstly, practitioners' examples of successful ICT-supported practice were sought through 10 focus group interviews in science departments selected via corroborated recommendation. Groups typically comprised three or four departmental colleagues who were regular users of ICT; they were asked to nominate and discuss practices in which ICT tools were deemed to support teaching and learning effectively. Following a review of nominations, three representative practices were selected for investigation in detail through 11 case studies, varied by practice, school, student group and topic (see Table 1). Participants exhibited well-developed and articulated pedagogical thinking about integrating technology use. Within- and cross-case thematic analyses drew on departmental focus group data, and the two lesson observations and follow-up teacher and student (group) interviews that were carried out in each case. Interviews were structured through a series of prompt cards designed to elicit teachers' thoughts about key actions in making the use of ICT successful. Prompts for pupils invited their thoughts on what they learned about the topic, or found difficult, how using ICT may have helped, and what the teacher did to help them learn.

Detailed findings concerning each practice are reported in separate papers (Deaney et al., in preparation; Hennessy et al., forthcoming, Hennessy et al., in preparation); here we summarise overarching themes that may generalise across technology use in science teaching more generally.

<Table 1 about here>

### 3.2 Findings

*Teachers exploited the affordances of dynamic visual presentation, interactivity and immediate feedback to render underlying scientific concepts and processes more salient and accessible to learners.* Dynamic representations enabled more efficient communication of complex concepts and acted as cognitive props, alleviating the need for students to formulate their own mental representations: ‘trying to show the fact that friction increases with acceleration is... very difficult’ whereas ‘animation takes a lot of the effort out [because] they can see it!’ (T), and ‘before it was just like a blur in the head but [with the simulation] you can see what is happening’ (P). Real-time data plotting stimulated discussion, prediction, hypothesis testing and questioning of anomalous results, for example when students in Teacher K’s lesson conjectured about the effect of opening a parachute in a simulated freefall scenario (see Figure 3). Collaborative investigation of the consensus everyday belief elicited (namely that the parachutist would elevate momentarily) was deliberately employed to provoke cognitive conflict. Teacher and student interviews confirmed that conflict had been successfully addressed through reconciling students’ prediction with the observed outcome: air resistance increased and speed decreased until forces were balanced and steady velocity was achieved.

The affordances were exploited via strategies for *focusing attention on key underlying concepts, relationships and processes*. Teachers designed lessons carefully to constrain the domain and accentuate the phenomena of interest (using simulations and animations to present simplified scenarios and datalogging to achieve ‘cleaner’, less ambiguous results). They guided students in exploring the consequences of manipulating variables – for example when emulating distance-time graphs using a motion sensor, or mixing coloured light with a simulation. Time gained through spending ‘less time at the board, drawing diagrams’ increased opportunities for strategic questioning and interpretation (e.g. analysing ‘shapes and patterns’ of cooling curve graphs whereas lower ability groups producing them manually could ‘lose the whole concept’). Opportunities to assess learning informally and to move students’ thinking on were capitalised upon through discussion of results or ‘prompting them step by step... to tell me what was happening’ especially whilst an application was running. Teachers were thus exploiting the direct manipulation of abstract representations of concrete objects in linking phenomena with theory (Hennessy & O’Shea, 1993).

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For example, after asking students to construct their own explanations of gaseous exchange in the lungs, Teacher C developed a logical scientific narrative by first annotating a projected diagram (Figure 3) to show the relative concentrations of oxygen and carbon dioxide in an alveolus, then animating it to demonstrate the process of diffusion. He exploited the dynamic visual representation and its interactivity while verbally communicating key aspects of the process:

<Figure 3 about here>

You can see the red blood cells all moving round the capillary... What's coming in now is just showing you the oxygen content... What's coming out you have just seen the carbon dioxide... So when you're breathing in you've got lots of oxygen here... lots of carbon dioxide in the blood compared to the alveolus, that diffuses out...

*Creating opportunities for student exploration, participation and manipulation* was perceived by teachers to be very important – as corroborated by the research literature and the Bristol University study described above. However most activity observed was teacher-directed and the rhetoric concerning discovery learning was not embodied in classroom practice. Constraints operating here comprised resourcing and technical issues, and existing pedagogical approaches and thinking. The latter are particularly shaped by concerns about classroom management and control, and by the systemic subject culture of secondary science which imposes tight curriculum time constraints. The difficulties consequently faced in interacting effectively with multiple students working in 'hands-on' mode (either with or without technology), mean that without timely teacher intervention individuals may flounder or develop their own 'idiosyncratic knowings' (Godwin & Sutherland, 2004).

Nevertheless, our findings demonstrated that pedagogic expertise for using technology effectively can be configured to overcome such constraints and concerns via interactive whole class teaching which supports collective scientific knowledge building. In such lessons (the majority), the emphasis was on student participation in cognitive rather than physical activity, and talk was typically focused upon clarifying or interpreting the phenomena made visible on the computer screen or board; students described how teachers 'talked us through it'. The above introduction to Teacher C's lesson on gaseous exchange exemplified this process; his students asserted that using a single whiteboard meant 'you can find things out together, and it's a lot easier'. Similarly, in the

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whole class activity with the motion sensor mentioned earlier, students experienced vicarious involvement through directing and observing peers' physical emulation of graphs: 'If somebody you know's done it, then you're more likely to remember it happened.'

Teacher K employed the projected freefall simulation (Figure 4) as a dynamic visual stimulus for questioning, conjecture and reasoning, and for focusing students' attention onto target concepts whilst manipulating the simulation himself (e.g. 'initially just weight acting on him, you can see air resistance there, getting bigger and bigger'). Students found this means of 'showing you how things worked' very helpful in increasing understanding; likewise, he 'asked us 'to get involved' and 'kept checking to see whether we actually knew what he was on about, instead of just keep moving on'. The teacher thereby used the technology effectively as a tool to support 'dialogic' communication (Mortimer & Scott, 2003) through eliciting students' knowledge and collaboratively evaluating it against the scientific model (as outlined above).

The practices observed could be described as fostering student participation in a collaborative community of inquiry (Sutherland, 2004) through a cognitively 'interactive' mode of teaching which proved effective in terms of student learning and motivation.

*Integration of technology with practical activities and other resources* was another common strategy used to enhance learning. Combined use of simulations and practicals enabled students to see 'what's happening in the real world' and to interpret observations in the context of theory. For example, Teacher R modelled osmosis using an egg immersed in saline solution, prior to discussion around a simulation.

Teachers also used IWB resources and animations to *support stepwise knowledge building*:

It's the building up, that construction of the understanding, bit by bit, on the screen, that really makes a difference.

Students could 'carry [learning] forward' and 'apply it to new situations' through revisiting interactive whiteboard pages, simulations and graphs. Questioning, written work and quizzes were often used to support this, particularly during plenaries. When Teacher C's students reviewed understanding of gaseous exchange on the interactive whiteboard 'they were arguing with each other and discussing whether things were right or wrong and why'. Some teachers combined

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learning outcomes of technology with other activities and knowledge to develop understanding within and over a series of lessons. Finally, teachers tailored integration of technology by providing different levels of pace, challenge and explication. Teacher K had built up a library of resources on which he could draw in *responding to varying learning needs*:

I like to come into lessons with different activities ready to pull in; then you've got to talk to the kids, work out where they are, and build the lesson around them.

### 3.3 Conclusions

Practitioners are capitalising on the commonly available interactive technologies in many effective ways and devising new pedagogic strategies and forms of classroom activity accordingly. These serve to focus attention on key concepts, relationships and processes while introducing and interpreting new scientific ideas. However, a range of forceful internal and external constraints collectively act to obstruct full realisation of the interactive potential of ICT in the sense that the desired opportunities for student experimentation, reasoning and physical manipulation were observed to be limited in some of our contexts. The findings illustrate how pedagogic expertise for using technology effectively can, however, be adapted to situational constraints via interactive whole class teaching which facilitates conceptual change through engaging students in public expression and critical scrutiny of their own conceptions. This process offers an adaptive solution to the difficult and time-consuming nature of interacting effectively with multiple students working in 'hands-on' mode. Success of strategies for using technology to support collaborative investigation, prediction, interpretation and linking with prior learning was corroborated by students' feelings of vicarious involvement and reports of conceptual learning. Likewise, Kennewell (2004) describes how effective primary teachers using IWBs involve students through oral questioning, requesting contributions and setting mental tasks, such as "What If" questions, which 'actively' engage and challenge learners.

Our contention is that such success relies on teachers *exploiting the dynamic visual representation through using the technology as a powerful, manipulable object of joint reference* – to stimulate discussion and hypothesis generation as they describe and reformulate the shared experience for

students (Mercer, 1995). The teacher's specific role here is one of pointing out both similarities and differences between informal and scientific ideas, bridging the gap between them and hence helping to build up and make accessible the accepted 'scientific story' (Ogborn et al, 1996).

#### **4.0 Overall conclusions**

The studies reported here along with others emerging in the research literature could be said to reflect a shift away from the educational legacy of 'exemplary scientific practice' within the school curriculum as characterised by real experiments (Gooding 1990) towards a more 'naturalistic philosophy' – that people learn by *active intervention* in a concrete world (Giere, 2002) where tools such as simulation and animation may play a bigger role. Despite the advent of new technological tools, experiments with physical objects in the laboratory are still widely used in science and in education. According to Reiner & Gilbert (2004) they are considered a central *cultural epistemological tool* for learning: the genesis of scientific knowledge is promoted primarily through experimentation. Thought experiments or "What If" explorations, while entirely the products of mental activity, are also viewed as if they were empirical experiments (Sorensen, 1992). The technologies studied here can in fact be used as tools to support the processes of both empirical and thought experiments since scientific *reasoning* is the common underlying goal.

Providing opportunities for students to generate their own thought experiments may serve as a mechanism for revealing students' prior conceptions, but if such reasoning is ultimately to be productive, it needs to be informed – to select, build upon and make links with related concepts and across different contexts within a supportive learning environment. It is here that the skilful role of the teacher – in selecting appropriate resources, sequencing and structuring learning activities, adapting to particular learners' needs, and guiding students' experimentation, generation of hypotheses and predictions, and critical reflection upon outcomes – proves pivotal in moving students on from merely seeing the physical world towards knowing the physical world as a scientist. Teachers in our studies used simulations, datalogging, projected animations and other resources as tools to encourage and support prediction and to demonstrate scientific concepts and physical processes – thereby 'bridging the gap' between scientific and informal knowledge (Scott & Jewitt, 2003). They also integrated technology carefully with other practical activities so as to

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support sequential knowledge building, consolidation and application. Finally, they capitalised upon the lesson ‘time bonus’ and the associated increase in opportunities for strategic questioning, interpretation, informal assessment of learning and addressing cognitive conflict, both during conversations with individuals/pairs of students and in whole class settings. This teaching strategy is in keeping with Doise and Mugny’s (1984) research which suggests that group-generated conflict stimulates the joint construction of a more advanced concept which is then individually internalised. The technology thereby underpinned the ‘dialogic, discursive process [through which] we come to know’ (Bruner, 1996, p.93).

On one level, the technological tools and resources employed could be viewed as reducing the need for speculation because they offer unambiguous and readily acceptable representations of scientific concepts and processes. However, used as strategic components of guided instruction, the same technologies can become powerful tools in supporting speculative activity, addressing prior conceptions and enhancing understanding of the limitations of the target scientific theories.

Research of the kind reported here has design implications for both curriculum-related activities and emerging computer-based learning technologies, in terms of helping us to understand how the teacher capitalises upon the technology available in supporting students to construct links between scientific theory and empirical evidence. The pedagogical principles of Predict-Observe-Explain remain pertinent while embedding explanations into meaningful practice mediated by new technologies merits further exploration.

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## References

- Baggott, L. & Nichol, J. (1998) Multimedia simulation. A threat to or enhancement of practical work in science education? In Wellington, J. (Ed.) *Practical Work in School Science*. London, New York, Routledge.
- Baggott la Velle, L. M., McFarlane, A. & Brawn, R. (2003) Knowledge transformation through ICT in science education: a case study in teacher driven curriculum development. *British Journal of Educational Technology*, 34, 183-200.
- Becta (2003) Educational Research on Interactive Whiteboards -a Selection of Abstracts and Further Sources.
- Brown, J. S., Collins, A. & Duguid, P. (1989) Situated cognition and the culture of learning. *Educational Researcher*, 18, 32-42.
- Bruner, J. S. (1996) *The Culture of Education*, Cambridge, MA, Harvard University Press.
- Champagne, A. B., Klopfer, L. E. & Anderson, J. H. (1980) Factors influencing the learning of classical mechanics. *American Journal of Physics*, 48, 1074-1079.
- Coghill, J. (2003) The use of interactive whiteboards in the primary school: effects on pedagogy. *ICT Research Bursaries: A Compendium of Research Reports*. London, Becta/DfES.
- Deaney, R., Hennessy, S. & Ruthven, K. (in preparation) Teachers' strategies for making effective use of data logging in secondary science lessons. *School Science Review*.
- Doise, W. & Mugny, G. (1984) *The Social Development of the Intellect*, Oxford, Pergamon Press.
- Driver, R., Asoko, H., Leach, J., Mortimer, E. & Scott, P. (1994) Constructing scientific knowledge in the classroom. *Educational Researcher*, 23, 5-12.
- Driver, R., Guesne, E. & Tiberghien, A. (Eds.) (1985) *Children's Ideas in Science*, Milton Keynes, Open University Press.
- Giere, R. (2002) Models as parts of distributed cognitive systems. In Magnani, L. & Nersessian, N. (Eds.) *Model Based Reasoning: Science, Technology, Values*. Dordrecht, Kluwer.
- Godwin, S. & Sutherland, R. (2004) Whole class technology for learning mathematics: the case of functions and graphs. *Education, Communication & Information*, 4, 131-152.
- Hennessy, S., Deaney, R. & Ruthven, K. (in preparation) Developing pedagogical expertise for integrating use of the interactive whiteboard in secondary science.
- Hennessy, S., Deaney, R. & Ruthven, K. (forthcoming) Situated expertise in integrating use of multimedia simulation into secondary science teaching. *International Journal of Science Education*.

## DRAFT

- Hennessy, S. & O'Shea, T. (1993) Learner perceptions of realism and 'magic' in computer simulation. *British Journal of Educational Technology*, 24, 125-138.
- Hennessy, S., Twigger, D., Byard, M., Driver, R., Draper, S., Hartley, R., Mohamed, R., O'Malley, C., O'Shea, T. & Scanlon, E. (1995) A classroom intervention using a computer-augmented curriculum for mechanics. *International Journal of Science Education*, 17, 189-206.
- Howe, C., Tolmie, A. & Anderson, A. (1991) Information technology and group work in physics. *Journal of Computer Assisted Learning*, 7, 143-153.
- Kennewell, S. (2004) Researching the influence of interactive presentation tools on teachers' pedagogy. *Annual Conference of the British Educational Research Association (BERA, September 2004)*. Manchester.
- Lave, J. (1988) *Cognition in Practice: Mind, Mathematics and Culture in Everyday Life*, Cambridge, Cambridge University Press.
- Mercer, N. (1995) *The Guided Construction of Knowledge: Talk Amongst Teachers and Learners*, Clevedon; Philadelphia, Multilingual Matters.
- Mortimer, E. F. & Scott, P. H. (2003) *Meaning Making in Secondary Science Classrooms*, Milton Keynes, Open University Press.
- Newton, L. & Rogers, L. (2003) Thinking frameworks for planning ICT in science lessons. *School Science Review*, 84 (309), 113-120.
- Newton, L. R. & Rogers, L. (2001) *Teaching Science with ICT*, London, Continuum.
- Ogborn, J., Kress, G., Martins, I. & McGillicuddy, K. (1996) *Explaining Science in the Classroom*, Buckingham, Open University Press.
- Osborne, J. & Hennessy, S. (2003) Literature Review in Science Education and the Role of ICT: Promise, Problems and Future Directions. Bristol, Nesta FutureLab.
- Osborne, R. J. (1985) Building on children's intuitive ideas. In Osborne, R. J. & Freyberg, P. (Eds.) *Learning in Science: The Implications of Children's Science*. Auckland, Heinemann.
- Pol, H., Harskamp, E. & Suhre, C. (2005) Solving physics problems with the help of computer-assisted instruction. *International Journal of Science Education*, 27, 451-469.
- Reiner, M. & Gilbert, J. (2004) The symbiotic roles of empirical experimentation and thought experimentation in the learning of physics. *International Journal of Science Education*, 26, 1819-1834.
- Schoenfeld, A. H. (1985) *Mathematical Problem Solving*, Orlando, FL, Academic Press.
- Scott, P. & Jewitt, C. (2003) Talk, action and visual communication in teaching and learning science. *School Science Review*, 84 (308), 117-124.

## DRAFT

- Smith, A. (2003) Interactive Whiteboard Evaluation. MirandaNet Community Focus on Research and Dissemination.
- Sorensen, R. A. (1992) *Thought Experiments*, New York, Oxford University Press.
- Sutherland, R. (2004) Designs for learning: ICT and knowledge in the classroom. *Computers and Education*, 43, 5-16.
- Wellington, J. (2000) *Teaching and Learning Secondary Science - Contemporary Issues and Practical Approaches*, London, Routledge.
- Whitelock, D. & Jelfs, A. (2005) Would you rather collect data in the rain or attend a virtual field trip? Findings from a series of virtual science field studies. *International Journal of Continuing Engineering Education and Lifelong Learning*, 15, 121-131.
- Whitelock, D., Scanlon, E., Taylor, J. & O'Shea, T. (1995) Computer support for pupils collaborating: a case study on collisions. In Schnase, J. L. & Cunniss, E. L. (Eds.) *CSCL 95: The First International Conference on Computer Support for Collaborative Learning*. Indiana, USA, Lawrence Erlbaum Associates Inc.
- Wishart, J. M. (1990) Cognitive factors relating to user involvement with computers and their effects upon learning from an educational computer game. *Computers and Education*, 15, 145-150.
- Wynne, B. (1991) Knowledges in context. *Science, Technology and Human Values*, 16, 111-121.

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**Figure 1. Simulation of an investigation of the effect of temperature upon enzymes from Focus Educational Software**

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**Figure 2. Animation of charge within an electric circuit from Furry Elephant**

Figure 3: IWB diagram of gaseous exchange at the alveoli (teacher annotations shown in italics)

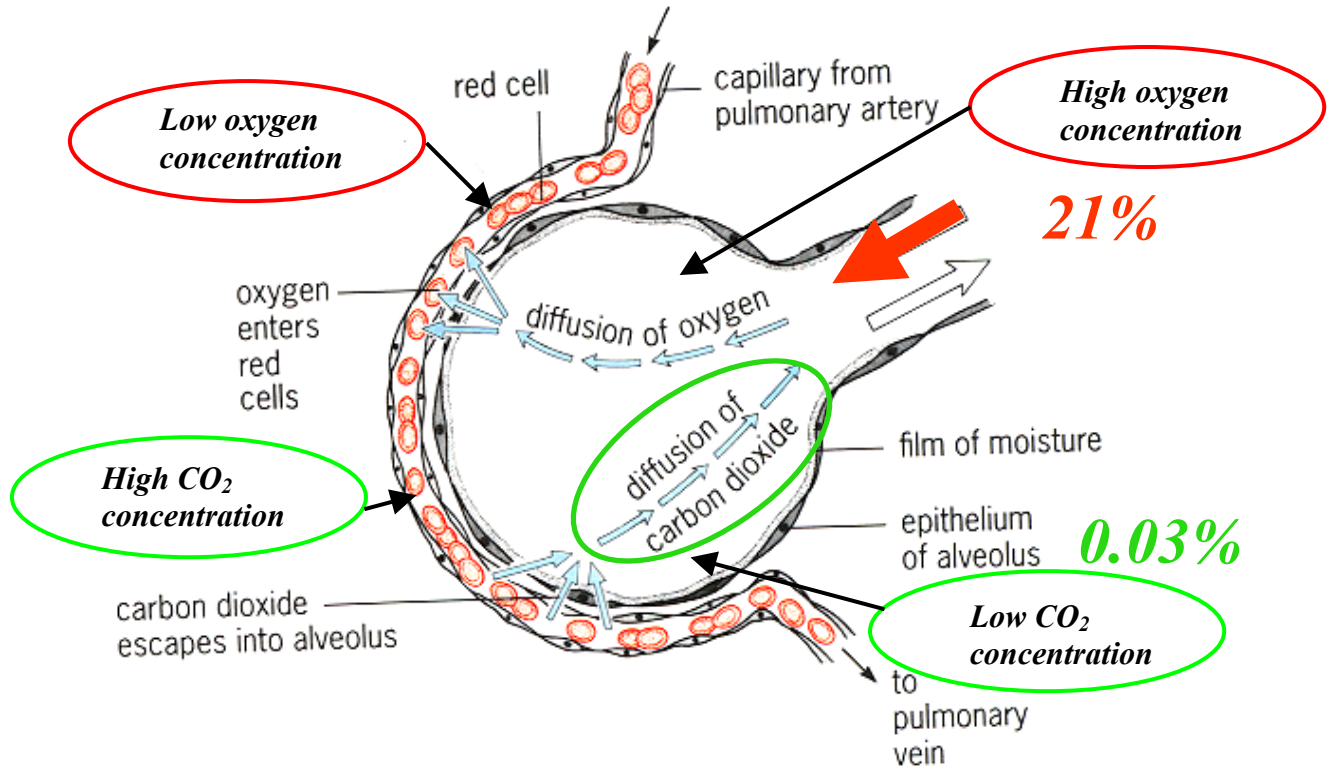
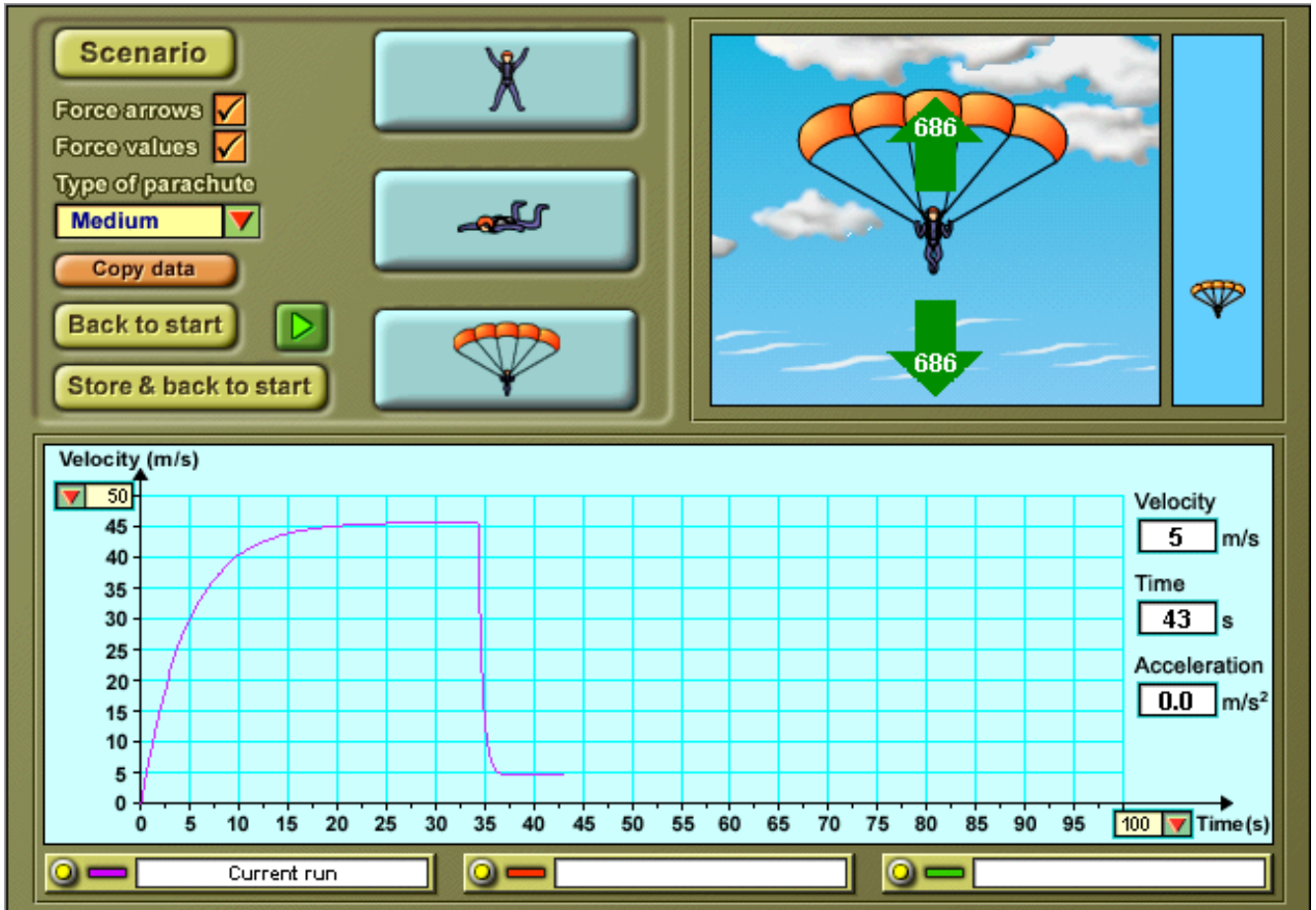


Figure 4: Terminal velocity simulation



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**Table 1: Lesson topics**

<b>Topic and Technology</b>	<b>Year Group/s</b>
<b>Simulations:</b>	
Diffusion and osmosis	10
Terminal velocity	9 and 11
Light mixing	8
<b>Datalogging:</b>	
Emulating/interpreting distance-time graphs	9 and 10
Effect of cooling rate on crystal size	10
Heat loss by radiation from different coloured surfaces	10
<b>IWB:</b>	
Gaseous exchange at the alveoli	10
Newton's third law of motion	10
Horizontal projection	10
Food chains	9
Preparing for ecology fieldwork	9