

Technology-integrated science teaching: Exploiting opportunities and adapting to constraints

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Introduction

Teachers' expertise is finely tuned to the teaching and learning setting. This expertise is flexing and responding to the introduction of digital technologies. By examining practice in different classrooms we have been able to understand how teachers adapt their actions and goals as they use ICT.

Our research is directly relevant to current practice. In school inspections for example, science teachers' *use of ICT* to promote learning is good or better in over four fifths of schools (Ofsted 2004, p.4). While there is some excellent practice, it is not shared widely. Our work offers a strongly analytic contribution to this sharing. It chimes with calls to look at strategies underlying successful practice (Becta 2003b; DfES 2003) and the need for well-informed approaches to effective applications in the curriculum (Ofsted 1999).

The study

As part of a wider project¹ we examined what educational technologies offer, and how secondary science teachers adapt to using them. The work builds on the established literature which highlights the importance of:

- activities which make implicit reasoning explicit
- teacher guidance which builds upon pupils' ideas
- teachers interpreting shared experience to bridge the gap between scientific conventions and informal ideas

Our study focussed on how teachers support learning using data loggers, software simulations and interactive whiteboards (IWBs).

- Simulations support learning by allowing a pupil to explore phenomena and handle experiments which would not be feasible in school.
- Data loggers automate the production of graphs in experiments. A live graph display offers immediate feedback such that changes can be monitored and technique adjusted.
- IWBs have recently become widespread in schools. They offer a whole class spontaneous access to a wide range of multimedia resources that can be manipulated and annotated. The literature indicates that projection helps students to visualise abstract knowledge (Becta 2003a; Smith 2003). Manipulation of objects on screen offers opportunities for knowledge building, although use often reinforces a teacher-centred didactic pedagogy lacking in response to individuals.

¹ 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.

We examined these tools at work in order to understand the teachers' tuning process, the strategies in use, and the rationale behind their interventions. Ultimately we would generalise across various technologies typically in use (see Barton 2004; Osborne and Hennessy 2003).

Methods

In Phase One of the research, we used multiple recommendations (from academic colleagues, subject advisors, practitioners and Ofsted reports) to identify 10 science departments regarded as relatively successful at integrating ICT into their practice. All were state-funded with specialist status and three were Technology colleges. Interviews were conducted with teachers to select those that articulated a well-developed pedagogy for using technology. This also led to the choice of multimedia simulation, data logging and interactive whiteboards for the study. In Phase Two, practices incorporating these three tools were investigated through 10 detailed case studies carried out with different schools, groups, teachers and topics. Lessons typically involved different classes from the same year. Afterwards, we interviewed teachers about strategies they had used to make the use of ICT successful. In addition, we sought the views of six students after each lesson.

Data analyses drew on lesson plans, schemes of work, lesson observations and transcribed interviews. Below we highlight overarching themes emerging from the analysis. (How each of the three technologies was used is described in separate forthcoming papers: (Deaney et al. in preparation; Hennessy et al. in preparation; Hennessy et al. submitted).

Findings

Some lessons incorporated introduction, exposition and discussion around a teacher demonstration, as in the data logging sessions. There was some 'hands-on' use of simulation by pairs, guided by printed worksheets and teacher intervention. With projected aids, the usual mode was whole class 'question-and-answer'.

1. Exploiting interactivity and dynamic visual presentation

Teachers perceived that IWB technology offered powerful interactivity, feedback, and an ability to modify material. They asserted that dynamic presentations render concepts more accessible. Animation and simulations portray abstract concepts efficiently. Learners can decode them more easily than static diagrams and descriptions.

Harnessing feedback

The instant impact of a large display stimulated interest. It facilitated all kinds of observation such as the effect of changing a variable. When a graph showed temperature changes in real time (*dynamic graphing*) pupils could appreciate cooling rates more readily than with static graphs. When pupils used a motion sensor to emulate a distance-time graph, feedback from a live graph created a tacit sense of distance.

Interaction with live data, compared to reading it after the event, was considered motivating and beneficial to learning. Real-time graphs allowed teachers to ask for predictions and this encouraged scrutiny of results. Immediate feedback assisted pupils' cognitive engagement with the activity.

When pupils were asked to speculate about opening a parachute during freefall the outcome was portrayed graphically by the simulation tool.

2. Focusing attention on underlying concepts and relationships

A key strategy to support learning with technology was ‘focusing’ or drawing attention to what needs to be understood. Teachers achieved this in various ways.

Framing and structuring tasks to increase salience of subject content

Teachers designed lessons around carefully structured and controlled situations, intended to accentuate the phenomena of interest – whilst guiding pupils in exploring the consequences of manipulating variables or interpreting results. Some teachers deliberately opted for teacher-led approaches *using a central projected display* in order to channel pupils’ attention more directly – both physically and mentally – towards target entities. This *pre-empted distraction* by ‘limiting the playing factor’, ‘keeping them on track’ and overcoming the ‘temptation to be flicking on all the buttons and things’.

When pupils used simulations, some teachers used highly structured worksheets, adapted for different abilities, to guide them. However, as discussed later on, such over-direction will restrict any exploratory use of the software.

Data logging was usually a demonstration activity that took place around other work. The teacher would lead a discussion of the results, pointing out salient features. Teachers remarked that a rehearsal was a critical part of using data logging effectively.

Simulations offer idealised representations that limit the range of operating variables to good effect. A teacher could focus on just one aspect of a concept, and be sure of always getting a ‘good clean graph’. *Careful customisation* of resources might be needed to channel attention in a particular direction.

Interactive whiteboards facilitated the use of a variety of multimedia. Teachers built resource banks for each topic, painstakingly selecting presentations, animations and video clips. The IWB software facilitates organisation and instant transitions between them. Teachers emphasised the need to become familiar with navigation and content in order to become ‘adept’ users. This involved previewing software to identify difficulties and prioritise points they might overlook.

Exploiting the ‘time bonus’

Teachers used ICT to ease and speed cumbersome tasks. This enabled them to focus on the key ideas as well as making time available for discussing results. Data loggers displayed temperature readings so rapidly that pupils could analyse a pattern in a cooling curve graph. Normally they might only draw the graph. Teachers reported how hands-on (simulation) activities gave them time to interact with pupils. They could observe ‘what was going on’ (G1) as they circulated, engaging learners in discussion and addressing their questions.

Gathering information on pupils’ understanding is an important feature of teaching. The computer display enabled them to gauge progress readily. With a simulation, diagram or animation to hand,

content was covered more quickly. Again, not having to draw repeatedly on the board, or handle physical apparatus, released time to concentrate upon learning, its consolidation and assessment.

Amplifying and interpreting representational display

Explaining concepts and interpreting visuals for pupils was another example of ‘focusing’. One teacher projected a data logged graph onto an ordinary whiteboard. To aid its interpretation he annotated and extrapolated it. (D). Another used the IWB highlighter to emphasise key words in a statement of Newton’s third law, and another pointed out operational features of a simulation of diffusion – to assist pupils in deriving their own interpretation.

Guiding pupils through activities with prompts or questions was regarded as important to help them make sense of experiences. Talk typically focused on what was on the screen as teachers capitalised on ways to move the students’ thinking forward. For example, prompting pupils to describe what was happening on screen reportedly helped them to ‘look’. The value of simultaneous explanation and illustration was corroborated by pupil comments:

And when he explains it he shows what he's talking about. Normally when we just talk about pictures or about diagrams we don't really know what it's about. R2/P

When pupils worked at their own machines, the teacher would explain concepts or ‘move them on’ periodically, so that they ‘found out what they should’. (C1). One teacher explained how he deployed data loggers according to the level of support needed to interpret the display:

If they were all using motion sensors in pairs it would be very different to talk them through each of their graphs, so it's good as a whole class exercise. The cooling curve experiment reliably gives a smooth line and they should be able to interpret it themselves. If it's real data, they sometimes need assistance to talk it through. K1

The replay of *animations or simulations* was a further means to focus aspects that were hard to grasp.

3. Building knowledge by integrating technologies with other activities

Using technology to support practical work and link it with theory

Teachers felt that technology could be used beside conventional practical experiments to enable pupils to see ‘what’s happening in the real world and what’s happening on the microscopic scale as well’ (FG). Teachers would employ a visual aid or a practical demonstration in conjunction with a simulation. For example, R illustrated osmosis with an egg immersed in strong saline solution. Later they would discuss an osmosis simulation. Follow-up practical work again reinforced understanding.

C used simulations so that pupils might ‘get an idea’ about practical work before they did it. Otherwise they would use it afterwards to gain insight into whatever they had observed. Similarly, teachers developed efficient routines that used data loggers beside other work. It offered pupils another perspective and reinforced their understanding. Sometimes a data logged graph (*of cooling*) was employed to develop concepts presented by a simulation (*of particles*).

Teachers used the IWB to *build up a process step by step*, using pictures and words to build up an explanation. For example they might pause an animation at various points. They might project a large ‘flexible camera’ image of a complex experiment, so enhancing visibility and engaging a

wider range of learners. Placing instructions on the IWB, prepared ahead of time, meant that pupils began and completed the set work much more quickly.

Using technology to support and consolidate sequential knowledge building

In some lessons teachers used technology to relate lesson content to prior learning and to reinforce that prior learning. This enabled pupils to engage with new activities. For example, pupils were expected to draw on graphical skills that had been developed in previous years. This 'skills training' also helped to guard against misinterpretation of data logged graphs display and allowed pupils to make faster conceptual progress.

Teachers used the annotation, revisit and reveal features of IWB software to build up concepts. One teacher said 'It's the construction of the understanding, bit by bit on screen, that really makes a difference' (B2). Hyperlinks enabled teachers to move between IWB resources – such that they could adapt to pupils' responses by jumping back a page.

Interactive whiteboard pages could be 'saved' and this offered a permanent record to revisit and follow up learning. A facility to replay data logging graphs enabled the teacher to review the pupils' understanding. Questions, quizzes and written work were commonly used to achieve this. Extrapolating from graphs produced by data loggers was seen as a key strategy 'to pull things together'.

It was particularly important to prompt students to make links between new knowledge gained through using ICT and prior learning. For instance, one teacher linked the three types of heat transfer introduced in his lesson to the familiar design of a thermos flask:

You could hear people say "Oh, that's why... your mum tells you not to break them because they're made of glass." ...it gives them something tangible that they can see and sort of analyse, and see the actual science behind it. Which is ...a good way of teaching science... to get them to think about practical applications of it, rather than just the concept itself in isolation. J2

Adaptation and differentiation

As might be expected, experienced teachers tailor their approaches to learners. They orchestrate activities to provide different levels of pace and challenge.

Those using interactive whiteboards mentioned how it enabled them to adapt lesson materials or 'pick and mix' from a range of activities. Teachers had built up libraries of electronic resources, and technology facilitated drawing on them expediently in response to student needs:

I come into lessons with a lot of different activities ready to pull in and then you've just got to talk to the kids, work out where they are, and then build the lesson around them... K2

4. Creating opportunities for learning through pupil exploration and manipulation

Rhetoric in the literature asserts the potential of ICT to increase opportunities for pupil manipulation of screen objects, for experimentation and for guided discovery learning. However, we observed that the use of data logging was predominantly teacher-led. Pupil interpreted cooling curves during teacher demonstration or they interpreted and emulated distance-time graphs as a whole class.

Limited opportunity for physical participation by learners was also observed in most lessons with the IWB. As one teacher recognised: ‘we probably don't make as much use of the interactivity as we could’ (O2). One teacher using an IWB (U) was the exception. She devised all her own resources and her lessons reportedly had ‘interactivity built in’. While her questions to pupils were ‘closed’, she ensured for example, that all pupils expressed their ideas as the class constructed a food web. She was contemptuous of using the IWB as a ‘big telly’ or OHP:

The word ‘interactive’ means it's not just me playing with the board, it's about interacting with the whole class.

There was a case where a teacher used a simulation to stimulate questioning and reasoning in a whole class setting (‘dialogic’ communication - Mortimer and Scott 2003). This teacher (K2) mediated by testing pupils’ hypotheses publicly, reconciling them with outcomes they could observe and explaining the underlying science.

More usually, pairs of pupils manipulated software at individual machines but they were confined by tightly structured tasks. Typically they were required to use specified settings, record results and sometimes also to explain them. The ‘authoritative’ discourse in these lessons emphasised the basic scientific relationships rather than building on or testing pupils’ ideas (Mortimer and Scott 2003). The pupils reported that they would like to have had more time to explore the software themselves. There was some variation between lessons but overall, the *opportunities for pupil participation appeared at first sight to be quite limited*.

Constraints upon increasing pupil participation and experimentation

The teachers’ rationale for demonstrating data logging and simulations included difficulties in supervising pupils or in helping them to interpret outcomes. It gave teachers full *control* over the procedure and the information to which pupils were exposed. One teacher described his role as ‘being there to modify the experience and not just to let them have free rein’ (A 1-2). For this teacher a ‘too open-ended’ approach had led to unproductive ‘playing’ while C asserted that pupils needed boundaries as well as ‘room to test some of their own ideas’ – because ‘they can’t resist pressing the buttons’. The preferred mode was thus to strike a balance between allowing experimentation and providing structured activity.

Limited *availability of resources* – sensors, computers and software – was a constraint operating upon ‘the hands-on, get-involved science’ which teachers wanted to offer. Moreover, teachers’ desired opportunities for pupils to explore and reason were reportedly hindered by *lack of time* and the ubiquitous ‘frustrating’ constraints of league tables, exam results, ‘having to get through the syllabus’.

Valuing and supporting active pupil participation

Despite various constraints, there was unanimous agreement between teachers and pupils that active *participation* was beneficial for learning. For example, teachers discussed the pupils’ *manipulation* of objects on the IWB in terms of ownership, involvement and increase in understanding. Likewise, excessive demonstration and unimaginative use could lead to the equivalent of ‘death by OHP’ (U).

Pupils described participation as ‘getting involved with what's going on in the lesson’. Teachers described how simulations supported pupil experimentation and permitted them to work at their own pace.

Encouraging the physical and verbal involvement of pupils was described as a key factor for success with the motion sensor (FG). One teacher (K) provided the initial graphs to emulate and he harnessed group support for pupils acting them out in front of the class. Immediate feedback helped pupils to conceptualise the process, beginning with a hypothesis about what kind of movement would match the graph (Figure 1):

P: She's got to go back... then stop for a few seconds then go forward.

T: And what can you tell me about her speed?

P: She's going forwards slower than she would go backwards. She's got to be steady.

K1 Obs

<Figure 1 about here>

K noted that learning took place when pupils became involved in the activity:

Initially there's a lack of confidence to put ideas forward. And then, given a couple of goes at it, literally everyone is shouting out, 'Stand there, go forwards, go faster!' and whatever. I think that's where you really see learning happening. K1

Strategic questioning and rapid pace were considered to be critical factors to engage pupils. Pupils themselves appreciated teachers organising activities to involve them in their learning:

He got us to join in so we could understand it a bit more. J/P1

Pupil reticence to contribute ideas or interact with a whiteboard was a potential pitfall as much as other pupils' idleness while the IWB was being used. Teachers devised strategies to pre-empt this such as having one group work at the whiteboard while others worked through a circus of activities. Others simply ensured that all were involved:

You inevitably get the more confident ones asking the questions and taking part. And then there are kids who are quite happy to sit listening. It's up to the teacher to involve as many students as possible and ensure there's no hiding place. They've got to concentrate because they know they're going to be asked questions. (O1)

It was seen as 'very much up to the teacher' to create a 'comfortable' atmosphere to foster collaboration:

...a spirit of high challenge, with a low risk of being belittled if they get things wrong. We can work together. B2

However this was only partially successful. Pupils were divided about whether their peers were supportive or critical. One pupil described 'watching people mess up' as fun. Some felt uncomfortable, including a pupil in the above teacher's lesson who had been coerced into coming to the front despite her reluctance:

Pupil: I didn't want to get it wrong.

Classmate: It's scary and I can't move it.... I don't like everyone watching me. That's scary as well. (B2/P)

Learning through cerebral involvement and participation in collaborative enterprise

Physical manipulation at the IWB was not the only way to promote involvement and participation. Using quizzes was an obvious example. However this phenomenon was particularly evident during teacher-led investigation which exploited the interactivity and dynamic visual presentation of the

various technologies, and attended to pupils' own conceptions, in the context of whole class teaching. For instance:

There's only one [interactive] whiteboard, so instead working in pairs or from books, you can find things out together,. (B2/Ps)

A powerful example was the resulting involvement which pupils described feeling when engaging with motion sensors indirectly via a peer's involvement, as in the emulation of motion graphs illustrated above:

If somebody you know's done it, then you're more likely to remember it happened. TMK/P2

In another lesson on radiated heat, pupils told us how being asked to predict which side of a Leslie cube would lose more heat fostered their participation.

In teacher-led lessons, the talk was typically about clarifying or interpreting what was on screen. Pupils described the teacher's role as 'talking us through it'. In one episode, K used a terminal velocity simulation (Figure 2) on screen as a stimulus to question and focus attention on target concepts while manipulating the simulation (e.g. 'you can see air resistance there, getting bigger and bigger'). K's pupils found this form of teacher mediation very helpful at supporting learning:

Instead of him just telling you, he was showing you how things worked. You could understand the movement.

<Figure 2 about here>

They relayed how dialogue fosters comprehension: he 'asked us to get involved' and 'kept checking to see whether we knew what he was on about, instead of moving on, so that we didn't get lost' (K2/P).

By encouraging conjecture, investigation and reflection, the teacher encouraged spontaneous contributions from pupils, building on their understandings. For example, the teacher asked about the forces acting on a simulated falling body. After two hypotheses citing 'equal forces', he asked for a class vote on what would happen when a parachute opened. The consensus was the common belief that the falling body rises slightly when a parachute opens. Testing this with the simulation showed that the prediction was wrong and pupils were asked to explain why.

T: We're going to wait until we reach the terminal velocity... watch that air resistance force. Now isn't that bizarre? It's actually where it was – and we all said it was going to go up... Who can tell me what's going on here?

P: It slowed down, and that meant there was less air resistance.

T: Yes, good. So basically a parachute opens, there's a big force going upwards. It's a slowing down force, so his speed reduces and reduces to the point where the speeding up force and the slowing down force are again equal and he moves at a constant speed. (K Obs2)

Subsequent interviews with pupils confirmed that they had learned that 'parachutes don't go flying up when you pull the cord', having previously thought that they did. The example demonstrates how the teacher skilfully began to close the 'gap' between everyday and scientific conceptions.

Summary and Conclusions

This study examined how pedagogy changes in response to the introduction of ICT into secondary science. The conclusion is mixed. Practitioners are capitalising on interactive technologies and devising new pedagogic strategies and activities. They use technology as a visual prop to stimulate class discussion and generate hypotheses. They talk pupils through concepts and processes, focus on key points, interpret scientific ideas and point out conflicts between those and pupils' informal ideas. Saved lesson time increases opportunities for interpretation, strategic questioning, and informal assessment of learning.

Integration of ICT with teaching and learning activities supports knowledge building and consolidation and application to new contexts. Although ICT can be adapted to different needs, its exploitation is limited by forceful constraints. These include resourcing, technical and classroom management issues. A content-loaded, formulaic science curriculum also drives teaching and learning. These constraints shape teachers' pedagogical approaches and obstruct the full potential of ICT from being realised. While practitioners (and the research literature) endorse certain exploratory activities as important for learning, in some contexts we observed limited opportunities for pupil reasoning, experimentation, and physical manipulation.

The findings also illustrate how teachers can adapt their pedagogic expertise with technology to the constraints operating. In particular, having multiple pupils work at the IWB is time consuming, while individuals working in 'hands on' mode at machines in the absence of timely intervention may flounder or develop incorrect ideas. Interactive whole class teaching simultaneously serves to overcome these difficulties and allows teachers to build scientific knowledge through collaborative investigation, prediction and discussion. Pupils' scrutiny of their understanding and its public expression through these activities facilitates their conceptual change. Successful strategies here were corroborated by pupils' feelings of involvement – vicariously through cognitive activity – and their reports of conceptual learning.

We conclude that success relies on exploiting dynamic visual representations as a reference point in order to exchange ideas, negotiate meanings, build knowledge, and restructure problems. A supportive classroom culture is characterised by structured activities and interactions which promote teachers' insights into pupils' thinking, and vice versa. These incorporate proactive and responsive guidance that continually assesses and accommodates learners' various and shifting needs. The teacher's role is to point out differences between informal and scientific ideas, bridge the gap between them and make accessible the 'scientific story'. Our research illustrates how practitioners are rising to the challenge and exploiting powerful technologies in ways which stimulate this kind of learning.

Acknowledgements

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Figure 1: Distance-time graph recording a student's motion beside a pattern they tried to emulate

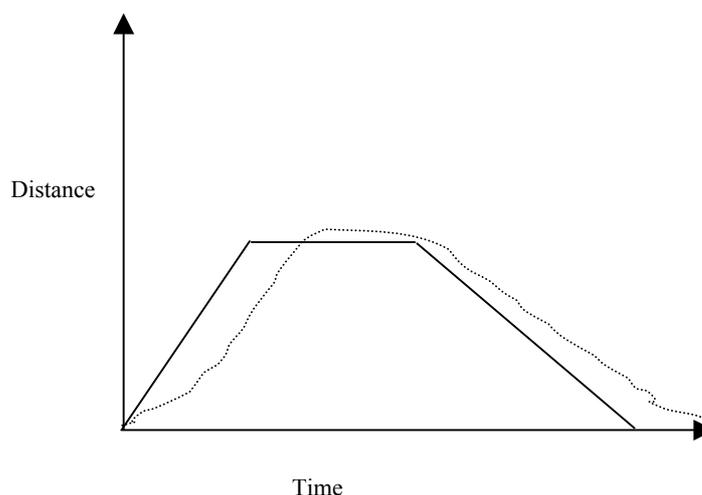
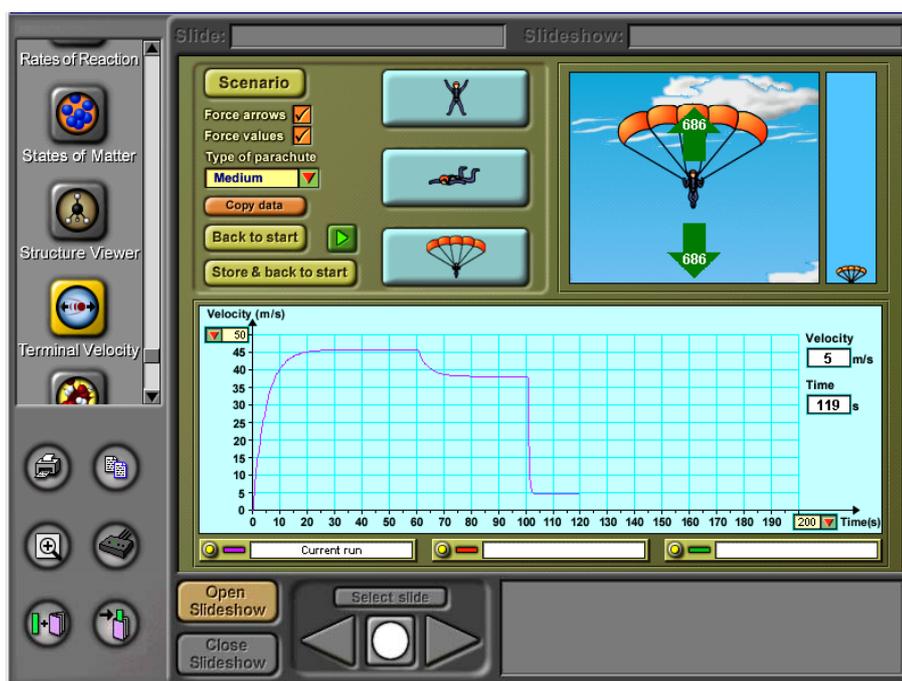


Figure 2: Terminal velocity simulation



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Table 1: Case Study Details

Teacher	Topic and Technology	Year Group/s
	Simulations:	
R, C	Diffusion and osmosis	10
G, K	Terminal velocity	9 and 11
A	Light mixing	8
	Data logging:	
J, K	Distance-time graphs	9 and 10
D	Effect of cooling on crystal size	10
E, J	Radiated heat from coloured surfaces	10
	IWB:	
B	Gaseous exchange at the alveoli	10
B	Newton's third law of motion	10
G	Horizontal projection	10
U	Food chains	9
U	Preparing for ecology fieldwork	9