TEACHING AND LEARNING PRIMARY SCIENCE WITH ICT

TEACHING AND LEARNING PRIMARY SCIENCE WITH ICT

Edited by
Paul Warwick, Elaine Wilson and Mark Winterbottom

Open University Press

Open University Press
McGraw-Hill Education
McGraw-Hill House
Shoppenhangers Road
Maidenhead
Berkshire
England
SL6 2QL

email: enquiries@openup.co.uk
world wide web: www.openup.co.uk

and Two Penn Plaza, New York, NY 10121-2289, USA

First Published 2006

A catalogue record of this book is available from the British Library.

ISBN-10: 0335 21894 6 (pb) 0335 21895 4 (hb)
ISBN-13: 978 0335 21894 3 (pb) 978 0335 21895 0 (hb)

Library of Congress Cataloging-in-Publication Data
CIP data applied for

Typeset by RefineCatch Limited, Bungay, Suffolk
Printed in Poland by OZ Graf. S.A.
www.polskabook.pl

CONTENTS

LIST OF CONTRIBUTORS

Paul Warwick is a lecturer at the Faculty of Education University of Cambridge (UK) and is engaged in a range of research and teaching activities that link directly with his interests in primary science education and to the professional development of trainee and beginning teachers. Previously he was a primary school deputy head teacher and an adviser for science for a local education authority. He is a member of the editorial board responsible for developing web-based materials associated with *Reflective Teaching* (Pollard *et al.* 2005). His recent publications include work on procedural understanding, data interpretation and the scaffolding of speech and writing in primary classrooms. His interest in the learning affordances of new technologies for primary science can be traced to his work in the 1990s on data logging in the primary classroom and has been stimulated by recent work on a Gatsby-funded research project with a primary school cluster in Cambridgeshire.

Mark Winterbottom taught science in upper schools in England for five years. During that time he was head of biology, ITT mentor, newly-qualified teacher mentor and lead-teacher responsible for developing interactive learning activities across the school using ICT. Mark has written a variety of textbooks and a handbook for newly qualified teachers of biology. He joined the Faculty of Education at the University of Cambridge (UK) in 2002 and teaches on the Science/Biology secondary

PGCE course and on the BA in educational studies. His research interests are in ICT and the psychology of education.

Elaine Wilson has taught secondary science in a range of schools. She is now course leader for secondary science at the Faculty of Education University of Cambridge and is involved in initial teacher education and early careers professional development. She has published work on activity theory and on classroom-based action research projects. Her current research involves working with new teachers in their early years of teaching. Elaine is a Higher Education Academy National Teaching Fellow and is using her prize money to develop a science education website.

Colette Murphy is Head of Learning and Teaching (pre-service) at the Graduate School of Education, Queen's University Belfast (UK). Before coming to Queen's in 1999 she was a primary science teacher educator (principal lecturer) at St Mary's University College, where she was also director of the in-service programme. She has been involved in several short and long term science development projects in primary schools in Northern Ireland and has been commissioned to deliver programmes for primary teachers organised by the Education and Library Boards. She has delivered practical science programmes for primary school teachers all over Northern Ireland and the Republic of Ireland, including the ASE Certificate in Primary Science Teaching, DASE modules in primary science and the Certificate in Professional Development for Teachers (Primary Science). Her principal research area is in primary science teaching and the use of ICT to enhance it. She directed the AZSTT-funded Science Students in Primary School (SSIPS) project and is currently directing the Science in the New Curriculum (SiNC) project, also funded by the AZSTT. Colette is a reviewer for three international education journals and is a member of the editorial board of the *International Journal of Science Education*.

John Williams has worked in primary education for over 30 years as class teacher, head teacher, adviser for science, governor and as a senior lecturer in higher education. As a head teacher in Kent, his school was one of the first in the country to use computers for teaching primary age children. He has written over 20 classroom books on primary science and design and technology. He has recently retired from full-time teaching at Anglia Polytechnic University, where he was the admissions tutor and senior lecturer responsible for the teaching of design and technology to trainee teachers. By dividing his time between Italy and the UK he remains involved with primary education, lecturing, supervising students in schools and, of course, writing. His other interests include research into various aspects of the history of science.

Nick Easingwood is a senior lecturer for ICT in education and acts as the ICT coordinator for the School of Education, Anglia Polytechnic University in Chelmsford, UK. He leads a post-graduate certificate of education secondary ICT course and contributes to primary and other secondary initial teacher education courses as well as in-service Bachelors and Masters degree courses. Having himself spent 11 years as an Essex primary school teacher, he maintains regular contact with schools through visiting students on their school experiences. His research interests include the development of online resources for student teachers and their ICT capabilities on entering higher education. His publications include *ICT and Literacy* (2001) which he jointly edited, a contribution to the second edition of *Beginning Teaching, Beginning Learning* (2002), *ICT and Primary Science* (2003), and *ICT and Primary Mathematics* (2004).

Derek Bell is Chief Executive of the Association for Science Education and has extensive experience not only of teaching and learning in science but also of the wider range of education issues including teacher education, higher education, subject leadership in schools, research, project management and network development. He has taught in schools and higher education institutions and been involved in science education research and development including the coordination of a major curriculum project. In addition he has undertaken a wide range of consultancies in the UK and overseas and is a member of several advisory/expert panels including the National Co-ordinators Group for the National Network of Science Learning Centres, the WISE National Co-ordinating Committee and the Astra-Zeneca Science Education Forum. He is a member of the Board of the Science Council, the Engineering Technology Board (ETB) and SETNET. From 2002 to 2004 Derek was Chair of the Wellcome Trust Society Awards Panel. Throughout his career Derek has maintained a strong and active interest in the enhancement of teaching and learning in science and is keen to strengthen the links between science, technology, engineering and mathematics through new and existing partnerships across the education, industrial and business sectors.

Adrian Fenton works as the curriculum support manager for the Association for Science Education (ASE). He has been the project officer leading Inclusive Science and Special Educational Needs developments in collaboration with NASEN, with outcomes including the Inclusive Science CD-ROM and website www.issen.org.uk. This has led to a continuing involvement with schools and organisations, writing articles for various journals and delivering professional development training. He has contributed to ICT in Science developments in collaboration with Becta, is part of the development team for Science UPD8 www.upd8.org.uk and has a broad understanding of curriculum developments and assessment, providing support for current science teachers. As a qualified science teacher (with a physics specialism) he has a broad experience of teaching in differing environments (1993–2001) including mainstream science teaching, teacher training with VSO in Tanzania and previous work with deaf students in higher/further education.

Ben Williamson is a learning researcher at NESTA Futurelab (UK), a not-for-profit initiative established to investigate the potential of new technology in learning. His research interests are learning outside school, literacy and ICT, the potential of videogames in education and participative approaches to new technology design. Previously, he trained as an English teacher at Bristol University and taught at a local secondary school. Ben is also currently a doctoral research student at the University of the West of England and a visiting fellow at Bristol University.

Patrick Carmichael is a lecturer in the Faculty of Education, University of Cambridge (UK) where he principally teaches on MEd programmes. He was previously Director of the MA in IT and Education at the University of Reading and has taught science and ICT in secondary, primary and special schools, mainly in London. He is also a member of 'Learning how to Learn' an ESRC-funded project exploring the development of formative assessment practice in classrooms, schools and networks.

Ruth Kershner is a lecturer at the Faculty of Education University of Cambridge (UK), with teaching and research interests in the psychology of learning and intelligence, the primary classroom as an environment for learning and special educational needs and inclusion. She has previously worked as a lecturer at Homerton College, Cambridge, and before that as a learning support teacher, primary teacher and childcare worker. Her current research is in the areas of the developing uses of ICT in the primary classroom environment, gender and special education, and teaching strategies for children with learning difficulties.

John Siraj-Blatchford is a lecturer at the Faculty of Education University of Cambridge (UK) and Associate Director of the ESRC Teaching and Learning Research Programme. His experience of teaching and researching in early years classrooms has been considerable. His publications include *Supporting Science, Design and Technology in the Early Years* (1999, with Ian MacLeod-Brudenell), *Supporting Information and Communications Technology in the Early Years* (2003, with David Whitebread), *101 Things to do with a Buzz Box: A Comprehensive Guide to Basic Electricity Education* (2001), *Developing New Technologies for Young Children* (2004) and an edited account of the 11 m. € Experimental School Environments (ESE) initiative from the European Commission Intelligent Information Interfaces (i3) programme. His latest book is a curriculum development guide to *ICT in Early Childhood Education* (2004, with Iram Siraj-Blatchford).

Helena Gillespie is a tutor in the School of Education and Lifelong Learning at the University of East Anglia (UK). She specialised in working with children with special educational needs in mainstream settings and has taught for ten years across the primary age range. She has published in a range of journals and books on primary education and in the field of information technology. Her research interests centre around learning environment and virtual learning environments.

Angela McFarlane is a professor at the Graduate School of Education, University of Bristol (UK). She is a director of the TEEM project on evaluation of digital content in the classroom, and is on the steering committee of the NESTA Futurelab project. Angela has a PhD in biological sciences and has taught science at school level for five years. She ran a software research and development unit at Homerton College, Cambridge and has experience of educational software development in a range of subjects including science. In addition, Angela has designed and directed national research and evaluation projects on ICT and learning, and was part of the team that designed the longitudinal study of the impact of networked technologies on home and school learning – Impact2. She was a member of the OECD expert group on quality in educational software and the first Evidence and Practice Director at Becta, the UK government agency for ICT. Her current research includes the role of e-learning in professional development, ICT in science education and computer games in learning.

Reference

Pollard, A., Collins, J., Simco, N., Swaffield, S., Warin, J. and Warwick, P. (2005) *Reflective Teaching* (2nd edn). London: Continuum.

ACKNOWLEDGEMENTS

We are grateful to the following companies, organisations and people for granting permission to use screenshots and other materials in this volume:

- Data Harvest © for screenshots of 'Sensing Science' in Chapter 3.
- Black Cat © for screenshots of 'Information Workshop' and 'Number Box' (Granada Learning Ltd, Television Centre, Quay Street, Manchester M60 9EA) in Chapter 3.
- Soda Creative/NESTA Futurelab (© 2004) for screenshots of 'Moovl' in Chapter 5.
- Kidspiration © for the mind maps created on 'Kidspiration' software that feature in Chapter 7.
- Professor G.K. Salmon, University of Leicester, for the five-stage model of e-moderating used in Chapter 9, http://atimod.com/e-moderating/5stage.shtml (Salmon, G. (2004) *E-moderating: the key to teaching and learning online*, 2nd edn. London: Kogan Page).
- Netmedia Education © for screenshots of Netmedia VLE images in Chapter 9.

The chapter authors would like to express their heart-felt thanks to the many primary teachers and children around the UK who participated in the projects that made the writing of this book possible.

1

CONSIDERING THE PLACE OF ICT IN DEVELOPING GOOD PRACTICE IN PRIMARY SCIENCE

Paul Warwick, Elaine Wilson and Mark Winterbottom

Good practice?

Let us think about a science lesson for primary pupils. In our fictional classroom the pupils are aged between 9 and 10 and the lesson has two central foci – understanding the insulating properties of materials and understanding the importance of fair testing procedures in experimentation. The teacher ensures a 'real-world' context for the practical investigation, linking it to ongoing design technology work on creating insulated cups to keep tea warmer for longer. Initially the teacher talks about fair testing, drawing on the children's understandings from recent work and thus setting the lesson within a framework of children's prior learning. Having set the procedural framework of the investigation, she encourages the children to express some of their initial ideas about why some materials may be better insulators than others. She demonstrates part of the task, deliberately ignoring some of the fair testing principles that have been discussed and inviting comment on her procedures. In doing so she uses the interactive whiteboard (IWB) connected to data-logging equipment and reminds the children of some of the functions of the data logger. Throughout this introduction the nature of group discussion around procedural and conceptual aspects of the task is modelled in the nature of the exchanges between the teacher and the children and in the guided interactions between the children themselves. In setting groups to work, the teacher emphasises that she is looking for a group consensus on what to say about fair testing in this experimental circumstance and clear evidence for asserting that one material is a better insulator than another. She provides a writing frame as a guide to thinking and discussion in the groups and, whilst most groups use more conventional equipment, one group is set to work using the IWB and data-logging hardware. During group work the teacher circulates, trying to ensure that group members have the opportunity to have their voices heard and challenging groups to justify their approach and findings. In drawing the lesson to a close the work of the group using the IWB is used as the 'springboard' for discussion of the results from all groups and differences between results are considered, primarily in terms of how investigational procedures might influence the nature of the evidence collected.

We have chosen this approach and context because it is familiar and also because it illustrates how ICT has become embedded in primary science teaching. Importantly, we also believe that this Year 5 classroom illustrates how social constructivism is informing pedagogical approaches. Social constructivism suggests that learning is a 'transactional' process which takes place through a complex interweaving of language, social interaction and cognition (Vygotsky 1978; Bruner 1985). These theories propose that the learner must be encouraged to make sense of newly developing knowledge within an already established personal knowledge framework. In our Y5 classroom pupils are encouraged to engage in actively constructing their own meaning through orientation, elicitation/structuring, intervention/re-structuring, review and application (Ollerenshaw and Ritchie 1993; Howe *et al.* 2005).

Wells (1999) goes further and suggests that pupils also need to have the opportunity to talk through their ideas and be allowed time for conjecture and argument. He believes that students need to be able to articulate reasons for supporting a particular concept and provide justification to their peers. The desired co-construction of knowledge takes place during this group interaction. Cooper and McIntyre (1996) describe the teacher's role in this transaction as providing the 'grammar and scripts' needed to set up the circumstances that will enable the learner to integrate this understanding through the process of 'scaffolding'. Cooper and McIntyre's definition of 'grammar' is the way the pupils behave in the learning situation and 'scripts' are the specialised language being introduced in the classroom. Science teaching can therefore be conceptualised in terms of introducing the learner to one form of the social language of science, namely school science. The teacher has a key role to play in mediating this language for students. Bruner (1985) draws attention to this central role of the teacher:

> . . . [the] world is a symbolic world in the sense that it consists of

> conceptually organised, rule bound belief systems about what is to be valued. There is no way, none, in which a human being could master that world without the aid and assistance of others; in fact, that world is others'.
>
> (Bruner 1985: 32)

Alexander argues that it is the interactions which take place in the classroom which have the biggest impact on learning, and that 'classroom discourse gives purchase, provides a balance and exercises power and control over the teaching and learning' (Alexander 2004: 424).

Mortimer and Scott (2003) draw too on the Vygotskian constructs of internalisation of concepts where the learner makes personal sense of the new social language with the active support of the teacher through the Zone of Proximal Development (Daniels 2000) from assisted to unassisted competence. They argue that it is through this interaction for 'meaning making' that learning takes place, and define the challenge in terms of the need to 'engage students in the patterns of talk, almost of argumentation, that are characteristic of science.'

This last notion is important when we consider what we are trying to achieve in science education more broadly. In the debate that surrounded the publication of *Beyond 2000* (Millar and Osborne 1998), it became clear that 'educating for scientific literacy' must necessarily include a focus on scientific understanding, not merely of content but of the nature of science. From this perspective consideration of the 'how and why' of scientific approaches to enquiry, together with the development of an understanding of science as a social process, can be seen as fundamental to science education (Driver *et al.* 1996). In trying to define just which 'ideas about science' may be central to a science curriculum for 5- to 16-year-olds, the Evidence-based Practice in Science Education (EPSE) project has identified the following elements: science and certainty; historical development of scientific knowledge; scientific methods and critical testing; analysis and interpretation of data; hypothesis and prediction; diversity of scientific thinking; creativity; science and questioning; and cooperation and collaboration in the development of scientific knowledge (Osborne *et al.* 2001). It will be clear that the approach taken in the classroom is fundamental to the development of such components of scientific understanding and that the approach taken is also likely to have a substantial effect on the attitudes of children towards science.

Placing this discussion in the reality of a 'target-oriented' education system Murphy *et al.* (2001), in looking at effective science teaching in Year 6 classrooms, confirm that *the* most commonly accepted measure of effectiveness used by schools, local education authorities (LEAs) and government is the end of Key Stage test results. They note that in the quest for this 'holy grail' two effective teaching models can be defined. The first is a teacher who might be described as a social constructivist (Light and

Littleton 1999), seeing the relationship between members of the class, including the teacher, as collaborative. Here, even though the curriculum may be subject structured, subject boundaries are often crossed by the teacher's approach as s/he looks at ways of making learning meaningful to the children by connecting knowledge that is presented in meaningful contexts. Concern about children *understanding* is of paramount importance. The best of such teachers get high end of Key Stage test results.

The second teacher type identified by Murphy *et al.* is one who represents science only as knowledge to be acquired. The subject is presented to the children as disconnected ideas and learned as disconnected ideas, which are re-inforced through revision testing. The teacher is in authority and the children tend to lack autonomy. Essentially the teacher inputs and the children output in the form of responses to the end of Key Stage tests. Interestingly, this is also a very effective model for achieving high test results. In the light of all that we have said so far, however, whether the children in the classes of such teachers are actually receiving a science education – let alone a good science education – must be strongly open to question.

In other words, what teachers of primary science do in the classroom, and how they do it, matters. In presenting our Year 5 class vignette we are arguing that good practice in primary science envisages learning as an active process of genuine engagement with the world, involves the teacher in scaffolding learning (Wood *et al.* 1976) through acting sometimes as an instructor and sometimes as a guide and facilitator, emphasises social negotiation and mediation between the children and the teacher and also between the children in group settings, helps children to become self-aware with respect to the intellectual processes that led them to specific conclusions, and encourages them to articulate ideas, explain, postulate and argue because the idea that 'scientific reasoning is a linguistic process' (Wollman-Bonilla 2000: 37) is taken seriously.

Where does ICT 'fit'?

If this is our view, in what ways might ICT be seen to 'fit' within this framework, and perhaps develop through providing new perspectives on pedagogy in primary science? Harrison *et al.* (2002) have shown how difficult it is to arrive at clear evidence of ICT directly enhancing teaching and learning, but there does now seem to be a gathering body of work suggesting that 'when teachers use their knowledge of both the subject and the way pupils understand the subject, their use of ICT has a more direct effect on pupils attainment. The effect on attainment is greatest when pupils are challenged to think and to question their own understanding . . .' (Cox *et al.* 2003: 3). Clearly, the use of ICT employed in our Year 5 lesson was influenced partly – as ever – by resource constraints, but most importantly it was influenced by the subject understanding and pedagogical intentions of the class teacher, with a clear emphasis on encouraging the pupils to challenge and develop their science understandings through collaboration and talk. The teacher demonstrated an understanding of the relationship between the ICT resources being used and the science concepts and processes that were the basis for the lesson objectives. She appreciated that the presentation of information using ICT can have an impact on the pupils' ability to engage with the subject matter of the lesson. And she recognised that the ways in which the pupils might be organised to collaborate in response to the lesson activity was, in part, influenced by the ways in which she wanted the ICT to be used.

This vignette therefore reflects some of the pedagogical principles for science education within ICT classrooms that are identified by Linn and Hsi (2000):

- that teachers should scaffold science activities so that pupils participate in the enquiry process;
- that pupils should be encouraged to listen and learn from each other;
- that teachers should engage pupils in reflecting on their scientific ideas and on their own progress in understanding science.

Recent developments in our understanding of cognition and metacognition seem to add weight to the prevailing assumption that the use of ICT is changing the pedagogical role of teachers and that it may have the potential to act as a catalyst in 'transforming' learning. One aspect of this may be in the development of the teacher's ability to develop powerful explanations (Moseley *et al.* 1999). In the classes researched by Moseley, primary teachers employed examples and counter-examples and involved pupils in explaining and modelling to the class as part of an emphasis on collaborative learning, enquiry and decision making by pupils. Even earlier projects (Somekh and Davies 1991) identified some transformational possibilities in the use of ICT, emphasising teaching and learning as complementary activities, with 'communicative learning' seen as central, and with technology seen as just part of the complex of interactions that takes place with learners.

Within our Year 5 class the use of data logging *might* be seen as simply replacing the existing technology of thermometers and removing the necessity of recording readings manually. Yet McFarlane *et al.* (1995) found that, with the use of data-logging hardware and software, the direct physical connection drawn between environmental changes (such as heat) and their immediate representation on the screen in the form of a line graph had a profound effect on pupils' later ability to note significant features on such graphs. Further, the pupils seemed more prepared to behave in a genuinely investigative manner, changing independent variables and analysing the effect of these changes, because they knew that it was comparatively easy to do so. Consider this, combined with the potential of the interactive whiteboard for opening up findings immediately to the whole class for discussion, and it begins to become clear that the nature of ICT tools themselves may have much to do with the quality of learning that may take place.

Yet it is clear that the tools themselves are only part of the picture. All that we have said so far illustrates that it is the mediation of those tools by the teacher, and the pedagogical practices adopted by the teacher in relation to those tools, that is likely to determine the extent to which the use of ICT in primary science is ever likely to transform learning. For example, Jarvis *et al.* (1997) evaluated the effect of collaboration by e-mail on the quality of 10- to 11-year-old pupils' investigative skills in science, in six rural primary schools. They found that the influence of the teacher was the crucial element in whether learning is enhanced.

Several themes thus seem evident when considering teachers' pedagogies and the use of ICT in science. A focus on developing a student-centred environment (Boyd 2002) seems to be connected with effective use of ICT. Linked to this, the development of new behaviours (Cox *et al.* 2003) to support collaborative learning in the classroom may be necessary in maximising learning potential for pupils, and this may include developing strategies to give pupils space to work with one another without the constant presence of the teacher. Indeed, Hennessey *et al.* (2005) found that the increased use of ICT did provide scope for such practices, with the teacher becoming more involved in supporting learning, keeping the pupils focused on the subject matter of the lesson and encouraging analysis. Some demonstrable cognitive benefits do seem to be associated with pupils sharing perspectives and understandings in collaborative learning supported by ICT. Fundamentally, the development of a conversational framework (Laurillard *et al.* 2000) seems central to developing learning with ICT in primary science. Different software (for example, for manipulating data, modelling or simulating activity) and different hardware (IWBs, video connected to the computer, data loggers) all require a different, carefully planned approach. Yet it is our view that the story of developing science ideas needs to be articulated in the classroom. As Wegerif and Dawes (2004: 86) suggest, 'children need to be given the opportunity to make their ideas public, that is, to participate in extended stretches of dialogue, during which concepts are shared and vocabulary put to use to create meaning.' It seems to us that developing and extending learning through using ICT in the primary science classroom has to be linked to this central pedagogical intention.

Contributing to emerging understandings

In this book we try to illustrate where we are with respect to the uses of ICT in primary science and to indicate, through chapters with specific foci, where we may be going. We have done this by combining chapters that are more practical and more theoretical in nature yet which are all founded in some way on existing practice and which broadly reflect the perspectives expressed thus far in this chapter. The book can thus be taken 'as a piece' and read in order, or individual chapters can be read in isolation depending on the reader's interests. To aid readers in their endeavour, the following outline of the book's chapters may prove helpful.

Chapters 2 and 3 are primarily about 'where we are now' and provide readers with a clear introduction to the uses of ICT in primary science education. In Chapter 2, Colette Murphy draws upon her recent work for NESTA Futurelab (Murphy 2003) in evaluating how ICT is currently being used to support primary science and in doing so provides another perspective on the 'good practice' themes of this chapter. She focuses primarily on how ICT might aid the development of children's skills, concepts and attitudes in science and on the development of primary teachers' confidence and skills in science teaching. She calls for specific and systematic research into various applications and their potential for enhancing children's learning in primary science. Finally, she suggests implications – drawn from her experience, research and reading – for software and hardware developers who are seeking to serve the needs of the learner and teacher in the primary science classroom.

In Chapter 3, John Williamson and Nick Easingwood argue passionately for the need for work in primary science to have a substantive practical base and illustrate how various forms of ICT use can be central to such work. They thus re-emphasise the need for active learning advocated by Murphy and then set about illustrating how the teacher's planning and classroom interactions are essential in promoting effective science learning in contexts where ICT is used. They give a clear overview of the numerous ways in which ICT might be used to enhance primary science learning, with their illustrations focusing primarily on applications that are concerned with the storage and use of data – databases, spreadsheets and data logging. In a piece that has practical examples of existing good practice at its heart, this chapter thus links with the previous one in providing a clear outline of practice and associated issues for those who may be relatively new to this area.

The central issue of inclusion is tackled by Derek Bell and Adrian Fenton in Chapter 4, where they argue that the key to genuinely inclusive science lies in the extension of existing good practice. They focus particularly on catering for the needs of those children with learning difficulties, demonstrating that science education can be enhanced where the development of pupil choice, self-advocacy, confidence and autonomy are promoted. Emphasising the central role of the teacher, they provide vignettes that illustrate how ICT might be used to boost physical accessibility to tools and ideas, to increase engagement with lessons and with ideas, to extend and develop the teaching dialogue, to aid the recording and reporting of work and, for the teacher, to extend the professional community's consideration of inclusion in science. In so doing they make a strong plea for appropriate and extended continuing professional development for teachers.

Chapter 5 introduces four chapters based upon the authors' personal research. In it, Ben Williamson considers how ICT might facilitate children's ability to create and manipulate visual illustrations and drawings of science concepts. In reporting on exploratory work with 'Moovl' software created by NESTA Futurelab, he aligns creative thinking with both conceptual and procedural thinking in science, showing how young children can be encouraged to engage in collaborative enterprise around drawing tasks where physical conditions such as air resistance can be duplicated. In the 'Moovl classroom' ideas are provisional and the iterative process of resolving approaches to a problem can provide real insights into children's scientific thinking. Links between notions of creativity and ICT are considered, as are the pros and cons of simulation software, before the potential of the Moovl software is explored. The multi-modal nature of representation and of thought is central to this chapter, as is the alignment of creativity with the development of understanding in science. Those interested in how a greater emphasis on children's creativity and visual literacy in the classroom can impact on their ability to become scientifically inquisitive will find this chapter provocative.

Continuing and developing the discussion about simulations and modelling in another context, Patrick Carmichael uses Chapter 6 to analyse the value of computer models to develop aspects of the 'characteristic and authentic' activity that scientists engage in when addressing positive, negative and neutral analogies in developing theory. Whilst noting the potential problems associated with the almost inevitable over-simplification of computer models, this chapter re-inforces the notion that ICT can prove to be a powerful tool in enabling young children genuinely to 'think like scientists'. The nature and role of analogical modelling in science is considered in a piece that is illustrated with excerpts from transcripts of interviews and conversations with young children who used a variety of computer programmes designed to represent individual animals, communities and whole ecosystems. The surprising sophistication of children's thinking in these circumstances, including an awareness of the computer itself as an 'active agent' in control of the simulation, reveals the value that such engagement might have in developing the capacity for a 'meta-level' of learning about the significance of modelling itself.

In Chapter 7 Paul Warwick and Ruth Kershner examine work carried out with pupils who used 'mind mapping' software to negotiate procedural and conceptual understandings in science lessons. This chapter looks in particular at the types of interaction and collaboration associated with the uses of such tools as interactive whiteboards and laptops within science activity in primary classrooms. An examination of the differences between pupil groups working independently at the IWB and on laptop computers allows a consideration of the affordances and constraints of differing hardware. In considering the affordances of the software, the focus on the use of mind mapping software enables a discussion of specific aspects of communication – such as questioning, explaining and pointing – together with an examination of how teachers might use a range of classroom tools to mediate learning. Interestingly, in examining the differences between the uses of the IWB with younger and older primary children the chapter emphasises this mediating role.

In asking for contributions to this volume it seemed essential to provide a contemporary account of the development of science and ICT in the early years. Though a volume in this series deals exclusively with ICT in the early years, we wanted to include a perspective related explicitly to science to give readers a sense of how 'pre-primary' learning in science can be seen as allied to, yet different from, later school experiences. In Chapter 8, therefore, John Siraj-Blatchford provides an analysis of the conjunction of ICT and 'emergent science' in the early years. He notes the problems of defining science learning for this age group but then takes the reader on a journey of discovery, pointing to the kinds of early years experiences that are likely to promote in children a strong orientation towards later scientific endeavour in their primary schooling. The strong link between learning in science and the 'playful curriculum', the centrality of the role of supporting adults and the importance of educators appreciating children's personal frameworks of understanding are all highlighted in a piece that then illustrates the relevance of ICT use from these perspectives. This chapter reveals the incredible capabilities of very young children and indicates that many of the uses of ICT suggested in other chapters for primary pupils are likely to be well within their capabilities.

In Chapter 9, Nick Easingwood and John Williams get 'a second bite of the cherry' within this volume. Here, they consider the development of science education outside the context of the school – specifically, they look at the science learning opportunities provided by museums and review the possibilities for enhancing this learning through the use of still and video digital technology. If science education is indeed a 'journey of enquiry', then this chapter reflects upon how that journey can be guided, recorded and developed through the dialogue that surrounds the planning, filming and presentation of experiences and activities with real objects in museums.

Chapters 10 and 11 look firmly ahead to possible futures. In Chapter 10, Helena Gillespie explores the possibilities inherent in the use of virtual learning environments (VLEs) for extending and developing children's work in science in the primary school. She considers how such environments might be used in compiling and cross-referencing ICT tools into subject-based or cross-curricular learning tools and notes the clear potential that this may have to develop Laurillard's (2002) intriguing notion of technology-based 'conversational framework(s)' that support learning. The key word in this chapter is surely 'imagine' – imagine how the capacity of such environments, now used increasingly with older pupils and adults, might impact on the primary science classroom in the future.

Finally, Chapter 11 gives the thoughts of someone with an international reputation in the world of education and ICT. In it, Angela McFarlane argues that the conceptualisation of the science curriculum has to change if we are to fully exploit the benefits of development in ICT in schools. She argues that if we are in the 'knowledge age' then education systems must change to prepare learners for this age. She notes that science is central to understanding the work of developing societies and yet the established science curriculum seems to do little to encourage reasoned, evidence-based discussion of science and science-related issues. The potential of ICT for developing webs of communication to support such discussion seems only to be partially exploited and one reason may be a somewhat slavish adherence to work based upon the three traditional school science disciplines. Angela thus provides a highly individual and thought-provoking piece to end this volume.

We hope that all readers, of whatever background, will find something of interest and value in this book and that it fulfils our intention of raising issues, debates and even arguments about the ways in which ICT can and should be used to enhance science learning in schools.

References

Alexander, R. (2004) *Towards Dialogic Teaching: Rethinking Classroom Talk*. Cambridge: Dialogos.

Boyd, S. (2002) *Literature Review for the Evaluation of the Digital Opportunities Project*. Wellington: New Zealand Council for Educational Research.

Bruner, J. (1985) 'Vygotsky: an historical and conceptual perspective', in Wertsch, J. (ed.) *Culture, Communication and Cognition: Vygotskian Perspectives*. Cambridge MA: Cambridge University Press.

Collins, S., Osborne, J., Ratcliffe, M., Millar, R. and Duschl, R. (2001) 'What "ideas about science" should be taught in school science? A Delphi study of the expert community'. Paper presented at the Annual Conference of the American Educational Research Association, Seattle WA.

Cooper, P. and McIntyre, D. (1996) *Effective Teaching and Learning: Teachers' and Students' Perspectives*. Milton Keynes UK: Open University Press.

Cox, M., Webb, M., Abbott, C., Blakeley, B., Beauchamp, T. and Rhodes, V. (2003) *ICT and Pedagogy: A Review of the Research Literature*. Norwich: HMSO.

Daniels, H. (2000) *Vygotsky and Pedagogy*. London: Routledge Falmer.

Driver, R., Leach, J., Millar, R. and Scott, P. (1996) *Young People's Images of Science*. Buckingham: Open University Press.

Harrison, C., Comber, C., Fisher, T. *et al.* (2002) *ImpaCT2: The Impact of Information and Communication on Pupil Learning and Attainment. Strand 1 Report*. London: DfES.

Hennessey, S., Deaney, R. and Ruthven, K. (2005) 'Emerging teacher strategies for mediating "Technology-integrated Instructional Conversations": a socio-cultural perspective', *Curriculum Journal*, 16 (3).

Howe, A., Davies, D., McMahon, K., Towler, L. and Scott, T. (2005) *Science 5–11: A Guide for Teachers*. London: Fulton.

Jarvis, T., Hargreaves, L. and Comber, C. (1997) 'An evaluation of the role of email in promoting science investigative skills in primary rural schools in England,' *Research in Science Education*, 27 (1): 223–236.

Laurillard, D. (2002) *Rethinking University Teaching: A Framework for the Effective Use of Learning Technologies*. London: Routledge Falmer.

Laurillard, D., Stratfold, M., Luckin, R., Plowman, L. and Taylor, J. (2000) 'Affordances for learning in a non-linear narrative medium,' *Journal of Interactive Media in Education*, 62.

Light, P. and Littleton, K. (1999) *Social Processes in Children's Learning*. Cambridge: Cambridge University Press.

Linn, M.C. and Hsi, S. (2000) *Computers, Teachers, Peers: Science Learning Partners*. London: Erlbaum.

McFarlane, A., Friedler, Y., Warwick, P. and Chaplain, C. (1995) 'Developing an understanding of the meaning of line graphs in primary science investigations, using portable computers and data logging software', *Journal of Computers in Mathematics and Science Teaching*, 14 (4): 461–480.

Millar, R. and Osborne, J. (1998) *Beyond 2000, Science Education for the Future*. London: Nuffield Foundation.

Mortimer, E.F. and Scott, P.H. (2003) *Meaning Making in Secondary Science Classrooms*. Maidenhead: Open University Press.

Moseley, D., Higgins, S., Bramald, R. *et al.* (1999) *Effective Pedagogy Using ICT for Literacy and Numeracy in Primary Schools*. Newcastle: University of Newcastle.

Murphy, C. (2003) *Literature Review in Primary Science and ICT*. Bristol: NESTA Futurelab.

Murphy, P., Davidson, M., Qualter, A., Simon, S. and Watt, D. (2001) 'Effective practice in primary science: a report of an exploratory study funded by the Nuffield Curriculum Projects Centre'. Unpublished. Available from Patricia Murphy at The Open University, Milton Keynes.

Ollerenshaw, C. and Ritchie, R. (1993) *Primary Science: Making it Work*. London: David Fulton.

Osborne, J., Ratcliffe, M., Collins, S., Millar, R. and Duschl, R. (2001) *What Should We Teach about Science? A Delphi Study*. London: King's College.

Somekh, B. and Davies, R. (1991) 'Towards a pedagogy for information technology', *The Curriculum Journal*, 2 (2): 153–170.

Vygotsky, L.S. (1978) *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

Wegerif, R. and Dawes, L. (2004) *Thinking and Learning with ICT*. London: Routledge Falmer.

Wells, G. (1999) *Dialogic Inquiry: Towards a Sociocultural Practice and Theory of Education*. Cambridge: Cambridge University Press.

Wollman-Bonilla, J.E. (2000) 'Teaching science writing to first graders: genre learning and recontextualisation', *Research in the Teaching of English*, 35 (1): 35–65.

Wood, D., Bruner, J. and Ross, G. (1976) The role of tutoring in problem-solving, in *Journal of Child Psychology and Child Psychiatry*, 17: 89–100.

2

THE IMPACT OF ICT ON PRIMARY SCIENCE

Colette Murphy

Introduction

This chapter reviews ways in which ICT currently impacts on the learning and teaching of science in primary schools. It evaluates how ICT is currently being used to support primary science in terms of how effectively it promotes 'good' science in relation to children's skill, concept and attitude development and to the development of primary teachers' confidence and skills in science teaching. In doing so it focuses primarily on 'where we are now' and reflects some of the broad perspectives on science and learning that are given consideration in Chapter 1. It also seeks to highlight the relative lack of research into how, when, how much and how often ICT can be used to enhance the development of children's science skills, concepts and attitudes. It calls for specific and systematic research into various applications and their potential for enhancing children's learning in primary science. Finally it suggests implications for software and hardware developers which are aimed at enhancing children's learning experience in primary science.

ICT and the improvement of children's scientific skills, concepts and attitudes in science

Primary science is centrally concerned with developing a beginning understanding of physical phenomena, materials and living things, laying the foundations for an understanding of physics, chemistry and biology respectively. Whilst these are the broad areas of study, primary science is not just concerned with knowledge but particularly with scientific ways of working and the ways in which these link to the development of both procedural and conceptual understanding. It is therefore 'child active', developing both manipulative and mental activity; and it is child focused, concentrating on the world as experienced by the child. Further, primary science education intends to develop an array of learning attitudes, some of which are shared with attitudinal learning intentions in other curriculum areas.

So, primary science has three central aims: to develop scientific process skills, to foster the acquisition of concepts and to develop particular attitudes:

Skills

The process skills are:

1. Observation – a fundamental skill in which children select out information using all our five senses.
2. Communication – the ability to say clearly through many media – e.g. written, verbal, diagrammatic, presentation software – what one has discovered or observed.
3. Measurement – concerned with comparisons of size, time taken, areas, speeds, weights, temperatures and volumes. Comparison is the basis of all measurement.
4. Experimentation – children often experiment in a trial and error way. To experiment means to test usually by practical investigation in a careful, controlled fashion.
5. Space–time relationships – ideas of time and space have to be developed. Children have to learn to judge the time that events take and the volume or area objects or shapes occupy.
6. Classification – children need to recognise, sort and arrange objects according to their similarities and differences.
7. The interpretation of data – the ability for children to understand and interpret the information they collect.
8. Hypothesising – a hypothesis is a reasonable 'guess' to explain a particular event or observation – it is not a statement of a fact.
9. Inference – based on the information gathered, a child, following

careful study, would draw a conclusion which fits all the observations he or she has made.

10. Prediction – to foretell the result of an investigation on the basis of consistent, regular information from observations and measurements.
11. The control and manipulation of variables – the careful control of conditions in testing which may provide a fair test and give valid results.

Whilst it is desirable that children acquire these skills it must be said that it is unlikely any of these skills can be taught or acquired in isolation but are involved and developed in many, if not all, science activities.

Concepts

Examples of concepts fostered by primary science learning are:

Time	Life cycles
Weight	Interdependence of living things
Length	Change
Volume	Adaptation
Energy	Properties of materials

Children will gradually acquire the above concepts, primarily through practical, scientific activities.

Attitudes

Science can also develop important learning attitudes and, some would argue, a child's character. Specific attitudes which are highly treasured by teachers and society and which can be achieved through hands on, enquiry-based investigations are noted in Figure 2.1.

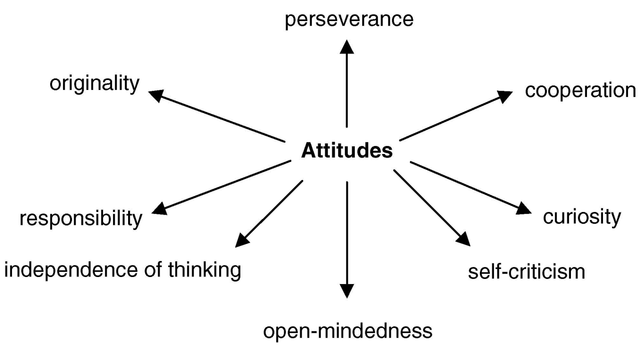


Figure 2.1 Attitudes that might be developed through science education.

The National Curriculum documentation for primary science in England and Wales interprets these skills, concepts and attitudes in the four sections of the Programme of Study as Scientific Enquiry (Sc1), Life Processes and Living Things (Sc2), Materials and their Properties (Sc3) and Physical Processes (Sc4) (DfEE/QCA 1999). The skill areas are identified as planning experimental work, obtaining evidence and considering evidence. There are variations in the Programmes of Study for Northern Ireland and Scotland. The Northern Ireland Programme of Study for primary science has reduced to two attainment targets: Exploring and Investigating in Science and Technology (AT1) and Knowledge and Understanding (AT2) (DENI 1996). The skills areas are planning, carrying out, making and interpreting, and evaluating. In Scotland, science is a component of the national guidelines for Environmental Studies (SOED 1993). Here the skills are categorised as planning, collecting evidence, recording and presenting, interpreting and evaluating, and developing informed attitudes.

How do children acquire these skills, concepts and attitudes?

If the development of these skills, concepts and attitudes are central intentions of primary science education, what kinds of activity are children likely to engage in to acquire them? The following would seem to be fundamental:

1. Observing – looking, listening, touching, testing, smelling.
2. Asking the kind of question which can be answered by observation and fair tests.
3. Predicting what they think will happen from what they already know about things.
4. Planning fair tests to collect evidence.
5. Collecting evidence by observing and measuring.
6. Recording evidence in various forms – drawings, models, tables, charts, graphs, tape recordings, data logging.
7. Sorting observations and measurements.
8. Talking and writing in their own words about their experiences and ideas.
9. Looking for patterns in their observations and measurements.
10. Trying to explain the patterns they find in the evidence they collect.

The teacher's role

Chapter 1 notes the centrality of the teacher's role in facilitating the emerging understanding of science primary pupils. In practical terms this means helping pupils to raise questions and suggest hypotheses, encouraging children to predict and say what they think will happen and encouraging closer and more careful observation. It also often means helping children to see ways in which their tests are not fair and ways to make them fairer, encouraging pupils to measure. For many practical enquiries pupils need help in finding the most useful ways of recording evidence so that they can see patterns in their observations. This may lead to the need for help in seeing the uses they can make of their findings. Central to all of this is the teacher's role in encouraging children to think about their experiences, to talk together, and to describe and explain their findings and thoughts to others.

The teacher's role in facilitating children's learning in science is explored more deeply in the next section which reviews the research into various aspects of children's science learning, particularly those linked to neuroscience.

The role of ICT in enhancing children's science learning

Recent studies of the brain, such as reported by Greenfield (2000), have led to 'network' models of learning. Such models consider ways in which computers appear to 'think' and 'learn' in relation to problem solving. They describe the brain behaving like a computer, forging links between neurons to increase the number of pathways along which electric signals can travel. As we think, patterns of electrical activity move in complex routes around the cerebral cortex, using connections we have made previously via our learning. The ability to make connections between apparently unrelated ideas (for instance the motion of the planets and the falling of an apple) lies at the heart of early scientific learning in terms of both creativity and understanding. As children explore materials and physical and biological phenomena, physical changes are taking place in their brains. These physical changes help to explain Ausubel's assertion over 35 years ago that 'the most important single factor influencing learning is what the learner already knows' (Ausubel 1968).

In the context of this discussion recent work in this area carried out by Goswami (2004) dispels three 'neuromyths'. The first is that the two hemispheres of the brain work independently – neuro-imaging has shown that there are massive cross-hemisphere connections in the normal brain and that both work together in every cognitive task so far explored. Secondly, it is not the case that education in certain tasks must happen at 'critical' times to be effective. Although there are sensitive periods for learning language, for example, this does not prevent adults from acquiring competence in a foreign language later in life. Thirdly, new neural connections can be made at any time if there is specific environmental stimulation.

The 'network' model of learning predicts that the active learning promoted by constructivist teaching approaches – in which children are actively engaged in knowledge construction – enables more pervasive neural connectivity and hence enhanced science learning. Of course, constructivist approaches present many challenges – the unique ideas and experiences 30 individuals bring to each new science topic; the challenge to these ideas that is presented by established scientific understandings of phenomena; the level of involvement in scientific enquiry required for each child; and the role of collaboration in group work that may be conducted with limited resources. So what role can ICT play in helping the learner to develop the skills, knowledge and attitudes associated with science and in helping the teacher to develop a constructivist approach to learning in her classroom?

McFarlane (2000a) illustrated the relationship between the use of ICT and the development of children's science skills (see Figure 2.2). Technology moves quickly, and, although McFarlane's scheme is still valid for mapping the process skills enhanced through using ICT during practical

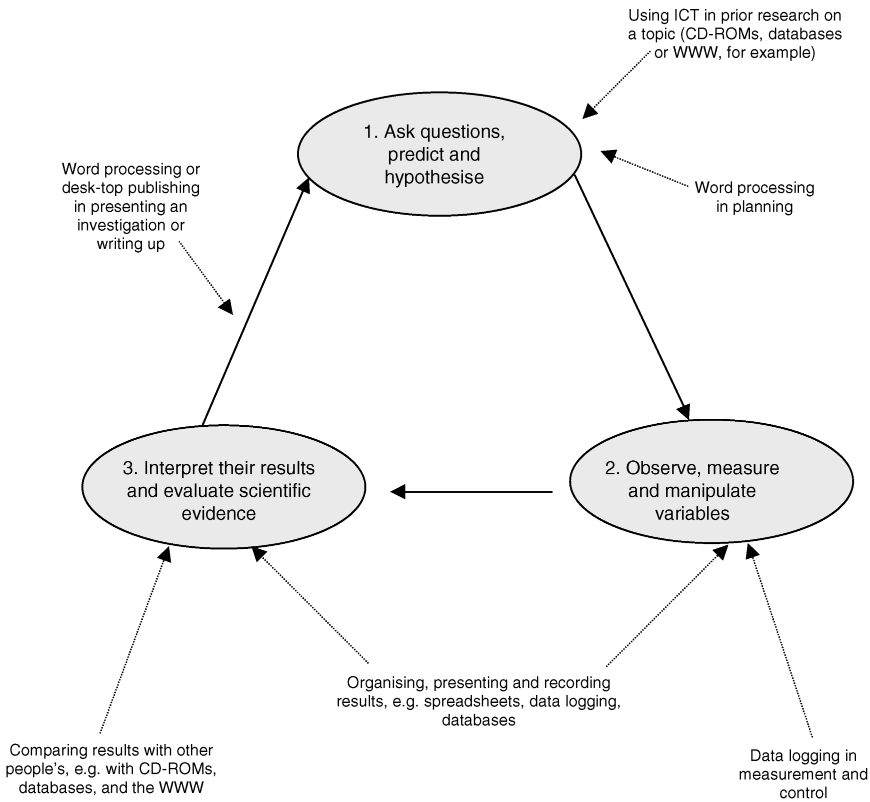


Figure 2.2 The relationship between the use of ICT and the development of children's science skills (McFarlane 2000a).

work, it might be usefully updated by including the recent increased use of multimedia in the writing up phase of science practical work and the extensive use of presentational technology, such as interactive white-boards or active slate systems. Perhaps the approach towards integration of ICT into primary science should focus more on functionality rather than specific ICT applications, for example: content versus content-free software, data logging, information handling and control technology. Which types of application, therefore, are best suited towards the development of the range of skills, concepts and attitudes outlined above?

O'Connor (2003) describes a methodology for implementing ICT into the primary science classroom which is rooted in constructivist pedagogy, 'where the children are agents of their own development'. She describes how multimedia is most effectively used as a tool 'to construct knowledge *with*', as opposed to learning *from*. She argues that the effective use of content-free software enables children to assume control of their own learning and illustrates this with a description of 10- to 11-year-old children creating PowerPoint presentations to demonstrate and communicate their understanding of electric circuits.

ICT can support both the investigative (skills and attitudes) and more knowledge-based aspects (concepts) of primary science. Recent approaches to science learning, particularly social constructivist methodologies, highlight the importance of verbal as well as written communication as being vital for children to construct meaning. ICT use can greatly enhance the opportunities for children to engage in effective communication at several levels. Communication, however, is only one use for ICT in the primary science classroom. Ball (2003) categorises four ways in which ICT is used in primary science: as a tool, as a reference source, as a means of communication and as a means for exploration. There is little *systematic* research on the use of ICT in primary science teaching, other than reports of how it has been used to support specific projects – for example, those included in the ICT-themed issue of the *Primary Science Review* in Jan/Feb 2003. Despite this, Chapter 1 has already made clear that the effective use of ICT in primary science is strongly linked to an understanding of effective pedagogical practice and in the following examples it is hoped that this link will become clearer.

The following section comprises an account of instances of practice derived from different sources in which usage of ICT in various primary science contexts has been reported (Murphy 2003). The author provides commentary on these from two standpoints, first, from working with students and teachers from a range of science backgrounds in the role of primary and secondary teacher educator, and, second, from directing a research project funded by the AstraZeneca Science Teaching Trust (AZSTT). In the project, science specialist student teachers co-planned, co-taught and co-evaluated science lessons with primary classroom teachers, using ICT to promote collaboration between students, teachers, teacher educators and subject matter experts (including curriculum developers, advisors and ICT specialists). The data from confidence audits carried out by students and teachers at the start and at the end of the project indicated a highly significant increase in students' confidence in ICT use during the project but less so for the teachers (Murphy, Beggs and Carlisle 2005). The ICT used for this work comprised a virtual learning environment (called *Blackboard*) which facilitated communication and document sharing between all participants, and training in software (called *Black Cat*) which could be specialised for primary science. When they were in college the science students had further opportunities to develop their ICT skills outside the classroom science context.

ICT as a tool

Spreadsheets

Spreadsheets are mainly used in primary science for data entry, tabulation and graph production, and form an essential element of fair testing and seeking patterns. Children at primary level are expected to use spreadsheets but not to create them for themselves, enabling concentration on the science aspects (Ball 2003). Poole (2000), however, warns that primary children have sometimes used spreadsheets without going through all the preliminary stages such as selecting axis scales and deciding on the best type of graph to explore patterns in the data. He suggests that the key issue is the pupil's ability to handle and interpret the data, so that the use of ICT for graphing needs to be part of a well-coordinated programme for teaching graphical skills. When the use of spreadsheets is considered in terms of the skills, concepts and attitudes summarised earlier it might be argued that the only added value of using a spreadsheet in terms of primary science is the speed with which the data can be presented graphically. This could indeed prove to be problematic because, if the children are not drawing the graphs for themselves, they may experience a 'conceptual gap' between measurements and their graphical representation. McFarlane and Sakellariou (2002), however, argue that using the graphing applications of spreadsheets can allow the teacher or pupil the choice of data handling to focus on presentation and interpretation rather than simple construction. The issue could be analogous to that of children using calculators routinely instead of mental arithmetic.

Databases

Ball (2003) is fairly dismissive of the value of databases in primary science, especially in relation to the fact that data or samples collected by the children are not often suitable for effective interrogation of the database. Feasey and Gallear (2001), however, provide some guidelines for using databases in primary science and illustrate two examples. In the first, 10-year-olds were building up a database about flowers. For some, much of the data collected may seem inappropriate for children of this age (length of anther, length of filament, length of carpel), raising questions as to the benefits of such an exercise in terms of scientific understanding or indeed for the development of ICT skills for children in primary school. However, in terms of understanding how measurement skills might lead to a greater understanding of variability in plant populations – raising questions as to why this variability might exist – this work might be seen as perfectly reasonable for such pupils and may well lead to the kind of discussions characteristic of the 'constructivist classroom'. The second example was a similar activity for infants who were creating a database of their class. This exercise might be viewed as more immediately relevant for pupils of this age. It enables children to produce bar charts and histograms for interpretation more quickly than by hand and, once again, it is the discussion around the meaning of these that leads to the development of scientific understanding.

Perhaps the most exciting use of a database with young children (6- and 7-year-olds) that I observed was an instance in which children were able to interrogate a prepared database of dinosaurs, whilst working with a science specialist BEd student. The children were fascinated to discover that some of these huge dinosaurs were vegetarian! They were stimulated to ask questions and wanted to find out more. In this context the children were using a database as a means of exploration. In addition to developing science knowledge it is clear that working with databases can directly enhance children's classification skills and, indirectly, could develop their powers of inference (Murphy 2003).

Data logging

Data logging is a highly versatile ICT tool for use in experimental science at any level. Higginbotham (2003) describes 6- to 7-year-old children 'playing' with a temperature sensor and discovering that they could find out whether it was in hot or cold water by watching the screen – they were effectively interpreting graphical data. McFarlane and Sakellarious' (2002) work presented supporting evidence of actual transferable learning take place. Ball (2003), however, argues that many primary teachers are not confident enough to use data loggers effectively in their science lessons. From my own experience of facilitating data-logging sessions with student teachers, I would add that many sensors are not sufficiently robust for use in the 'normal' classroom. Sensors that seem to 'work' perfectly well in one session may prove entirely useless in the next. That apart, the potential value of using sensors in primary science is considerable in terms of the development of the skills of observation, measurement, experimentation, space–time relationships, interpretation of data, inference, prediction and the control and manipulation of variables. The concepts of time and change can also be developed via the process of data logging, as can the attitude of curiosity and, if working in groups, children can learn to be cooperative in their approach.

ICT as a reference source

CD-ROMs

Amongst the most common ICT reference sources used in primary science classrooms are CD-ROMs. These range from encyclopaedic resources, such as *Encarta*, to the *ASE Science Year* CD-ROM, which contains a wealth of science-related activities. CD-ROMs are relatively permanent, physical entities which can be catalogued and stored like books. As such, schools and other institutions have 'banks' of CD-ROMs available for use. Undergraduate student teachers in a Northern Ireland University College who were science specialists preparing to teach in primary schools evaluated several of the most popular CD-ROMs which were used in primary schools. Their comments were most interesting since they were asked to evaluate in terms of their own enjoyment as well as from a teacher's perspective (Murphy 2003). Table 2.1 summarises some of the student

Table 2.1 BEd science students' comments on primary science CD-ROMs

Name	*Positive*	*Negative*	*Suggestions*
Light and Sound	Diagrams and animations	Not very exciting start Written explanations complex	More interaction Integrate assessment of pupil learning
Mad about Science – matter	Good graphics Games and rewards Flash questions – would keep children's interest	'Upper class' English accent Children would need relatively good knowledge of materials to benefit	Voice-over to read questions Use for only short time periods – games become repetitive
Mad about Science – 2	Voice-overs Good explanation of terms	No differentiation for different ability levels No instructions No 'second chance' to answer questions in games	Different levels 'Second chance' option for questions
I love science	Interactive diagrams Safety messages Reward system	Too difficult for 7–11 age range 'Word attack' confusing	

My first amazing science explorer (5–9)	Incentives and rewards Personal record and progress chart Varying difficulty levels Clues given to help answer questions Fill explanation of correct answers	Some parts too advanced for age range Could not find purpose for the worksheets	Programme adapted to take account of pupil's understanding before awarding 'badges'
My amazing human body	'Secret file' section	Too advanced for 6–10-year-olds – some questions difficult for a BEd science student!	
Magic School Bus	Entertaining and enjoyable Links body organs	Too much clicking of icons required Difficult navigation	
Science explorer 2	3D graphics Animations Virtual labs – book facility Website Safety warnings	Difficult animation; lack of instructions Boring voice-over Some investigations too complicated	Include an interactive 'character' as guide to involve children More colour, excitement and interaction Use only with small group of children
Science: forces, magnetism and electricity	Graphics and music	No explanation of experimental results Little variety	Only use for five minutes or so – becomes boring

views which could be useful for both developers and teachers when designing and using CD-ROMs.

The students' comments highlight the pedagogical issues surrounding the use of different CD-ROMs as reference sources. In terms of the skills, concepts and attitudes primary science aims to develop in children, the use of CD-ROMs has the potential both to enhance and to inhibit children's learning. The developers have a vital role in this regard to ensure that they provide a learning experience which ensures that children are highly motivated by the software to enable the development of specific skills, concepts and attitudes. For example, difficult navigation and lack of clear instructions are immediate 'turn-offs' for both teachers and children.

All software development should include several phases of formative evaluation by the target audiences. From my own experience of developing courseware, I can state that packages look, sound and run completely differently in the absence of input from the children at whom they are aimed.

The Internet

The Internet is used in primary science both as a reference source and as a means of communication. Problems of lack of access to the Internet in primary classrooms restrict its use in lessons, though this is changing dramatically with the 'revolution' in large group access being brought about by the introduction of interactive whiteboards (IWBs) in many primary classrooms. Even in the absence of such hardware, teachers are able to download and use many excellent resources with the children. It is also common for children to use the Internet as a reference source at home. Indeed it appears that children use the Internet more than teachers. A survey of more than 1500 primary children and over 100 primary teachers (November 2001) reported a highly significant different mean response ($p<0.001$), with 23 per cent of the children claiming to use the Internet often, compared with only 13 per cent of the teachers. There was no significant difference, however, between those reporting no use of the Internet – 54 per cent children and 55 per cent teachers. In the same study, 13 per cent of primary children responded that they often used a computer for homework (Murphy and Beggs 2003).

The Internet provides a wealth of resources for primary science learning and teaching. Cockerham (2001) has produced a resource called *Internet Science*, which details a series of activities aimed at 7- to 11-year-old children. These activities largely comprise comprehension questions based on children's navigation and interpretation of relevant websites. Such activities might aid children's concept development in specific content areas and have the potential to arouse curiosity and, depending on connectivity and the availability of specific URLs, might have a strong effect on developing the attitude of perseverance! More recently Becta (2002) produced guidance for using web-based resources in primary science.

An example of Internet use for a primary science investigation involving hundreds of schools took place in Northern Ireland in March 2002. Over 5,000 children took part in a Science Year project in which they used the Internet to enter and analyse their data. Children (or the teacher) entered either 'R' or 'L' into a prepared database to indicate which hand they used for the following tasks: writing their name and throwing a tennis ball into a box (for 'handedness'); kicking a tennis ball and hopping on one leg (for 'footedness'); identifying a quiet sound in a box ('earedness') and looking at a friend through a cardboard tube ('eyedness'). Children could obtain immediate feedback as to how their data fed into the total set and an update on the analysis. The study concluded that 'handedness' did not relate directly to 'footedness', 'earedness' or 'eyedness' (Greenwood, Beggs and Murphy 2002). As an exercise in understanding the importance of the collaborative, cooperative nature of scientific endeavour (Osborne *et al.* 2001) this could hardly be more striking.

ICT as a means of communication

E-mail and online discussion

The use of e-mail in primary science learning and teaching is restricted because not all classrooms are online. However, this is changing and the potential for children to exchange a wide variety of experiences and information with those from other schools, both locally and globally, via e-mail is huge, particularly for environmental projects. A current difficulty with teaching about global environmental issues is that children feel powerless to do anything about them and consequently do not change their behaviour in ways which could alleviate problems (Murphy 2001). Greater communication with children from other areas of the world would enable pupils to empathise more and consider the wider implications of their actions in an environmental context.

Using e-mail has the potential for enhancing children's communication skills in primary science, particularly as it enables children to communicate about science directly and informally with their peers. There is much progress to be completed in terms of connectivity in primary classrooms before this facility can be exploited on a wide scale, but the progress is encouraging.

Digital camera, PowerPoint and the interactive whiteboard

Apart from the more obvious e-mail and Internet applications, the digital camera, PowerPoint and interactive whiteboards have proved to be highly versatile in helping children develop a range of communication and other skills. Lias and Thomas (2003) described their use of digital photography in children's meta-learning. A class of 8- and 9-year-old children used photographs of themselves carrying out science activities to describe what they had been doing, their reasons for doing it, what they had found and why. The children's responses to the photographs (displayed on an interactive whiteboard) generated far more confident and fluent descriptions which needed a lot less prompting and support than had ever been observed previously. In addition, their responses were more detailed and complete. When tested several months later, the children's recall of the activity and their understanding of the associated scientific concepts were significantly improved when they were shown the photographs. Lias and Thomas (2003) aim to extend this work by using digital photography to help children to critically evaluate their own progress, identify ways to improve what they have done and to recognise the usefulness of what they have learned.

Presentation tools such as PowerPoint – and interactive whiteboards used for this purpose – provide excellent opportunities for children to consolidate knowledge, assume responsibility for and ownership of their learning, engage in high-level critical thinking and communicate their learning to peers, teachers and wider audiences. O'Connor (2003) illustrates slides developed by children as part of a presentation on electricity which she describes as an example of how ICT and primary science can be integrated and linked successfully.

In terms of skills, concepts and attitudes, presentation tools have enormous potential for enhancing children's learning in primary science. By preparing a presentation, children could be involved in communicating all aspects of planning and carrying out experiments, rehearsing hypotheses, describing methods and discussing their recording procedures. They might then be involved with data interpretation, inference and drawing conclusions, which would be required for them to 'tell the story' of their work to their peers. The attitudes of cooperation, perseverance, originality, responsibility, independence of thinking, self-criticism and open-mindedness can all be fostered. Having to communicate their understanding of scientific concepts, and perhaps answer questions based on that understanding from less informed peers, enables constructivist learning (Vygotsky 1978). I would argue that it is in the area of presenting scientific information, as reported by O'Connor (2003), that children's learning in primary science might benefit most by their classroom use of ICT.

ICT as a means for exploring

Control technology

ICT can be used in an experimental and exploratory manner allowing children a safe and supportive context in which to work (Dorman 1999), though the connections to mathematics, to design and technology and to the development of collaborative learning are, as yet, more obvious than are specific links to science education.

Simulators and virtual reality

Probably the least exploited use of ICT in primary science classrooms currently is exploration using simulators and virtual reality (Murphy 2003), though later chapters in this volume make it clear that this picture is changing. An example of simulator use is illustrated in the Teacher Training Agency (TTA, now the Teacher Development Agency –

TDA) guidelines for using ICT in primary science (TTA 2003). The teacher used a program that simulated the speed of fall of different sizes of parachutes. She scheduled groups to use the program on the classroom computers over a week. She emphasised that they were to predict the results of their virtual experiments before carrying them out and asked each group to write a brief collaborative report on what they had learned from using the program. The teacher did not intend the 'virtual lab' work to replace the practical activities, but felt that carrying out experiments on the computer was a good way to enable the children to predict and hypothesise using their knowledge of air resistance. They would get instant feedback to reinforce their learning of how air resistance operates.

Case study of integrating ICT into primary science

The Teacher Training Agency produced explicit guidelines and exemplification materials for using ICT in primary science aimed at mentors and initial teacher training institutions working with primary student teachers (TTA 2003). They illustrated their guidance with reference to three case studies in the areas of

- grouping and changing materials (6/7-year-olds);
- the environment and invertebrate animals in their school grounds (8/9-year-olds);
- forces (10/11-year-olds).

Each of the case studies indicates links to the curriculum documents and gives background information and notes about the context and computer resources. The case studies follow the investigations step by step, indicating teacher decisions about what, how and when to use different ICT applications, for example:

> The teacher found that the Internet and CD-ROMs did not provide as much useful information as the book sources she used. In addition, the books were portable and she was able to use them outside.
>
> The teacher knew that temperature and light levels could be measured using simple devices such as a thermometer or a light meter, but she wanted pupils to appreciate the way in which each habitat changed over a longer period. This was most easily done using a data logger. The teacher used a data logger, which did not need to be connected to a computer, to take readings of light, temperature and moisture over a 24-hour period.
>
> She decided to allow the use of the digital camera to take photographs of each animal because she realised that pupils would enjoy having photographs for use later in their work. She restricted each child to a

> single image to supplement their hand-drawn pictures. She felt that printing out each image 32 times (one for each child) would take too much time, be expensive and have little or no educational value. In retrospect, she felt that even this limited use of the digital images had little educational benefit especially since the quality of the close-ups was not good.
>
> She decided not to let pupils word process their writing this time, since she only had two computers available for this work and realised that it would take too long for each child to write his or her account using a computer. In any case, the two classroom computers were being used for searching for information and printing the images. The teacher wanted pupils to use the information from books and CD-ROMs selectively so she showed pupils how to make brief notes rather than indiscriminately using a whole entry.
>
> (TTA 2003)

Although clearly idealised and extensive, these case studies do provide a useful source of information about ways to use ICT in primary science. Comments relating to children's responses and classroom restrictions could provide valuable insights for software developers in the design of courseware for primary science.

Specific research areas to explore how ICT use can enhance primary science learning

Some questions raised in this chapter point towards gaps in the research into primary science and ICT. In relation to the role of ICT enhancing children's science learning, the question is raised about how ICT use can aid the constructivist approach to science teaching. More particularly, there is a dearth of research into which types of application might enhance different aspects of science learning. Is content-free software most useful in helping children to 'construct' and communicate ideas? If so, which applications are best suited, and how, for the construction of ideas and which for communication? Or is it the case that presentation software, for example, can enhance both processes?

When ICT as a tool is considered, are the use of spreadsheets and databases creating conceptual gaps in children's development of graphing and key construction skills? Indeed, do we need to acquire such skills in order to interpret, interrogate and manipulate data successfully? McFarlane *et al.* (1995) have suggested that the use of data logging with 'live graphing' can enhance an understanding of the meaning of graphs without the need for the mechanical skills of graph drawing. This raises a debate similar to that which raged with the introduction of calculators in schools. If graph-drawing skills are found not to be required for successful graphical interpretation, then ICT use can substitute for the less exciting aspects of scientific investigation such as the manual plotting of data. If not, then the two must be used in tandem, so that children can conceptualise how the data record was produced.

When exploring the use of ICT as a reference source, Table 2.1 presents reactions of student teacher users of a variety of CD-ROMs. A more systematic survey of attitudes of teacher and child users towards CD-ROMs might lead to the incorporation of particular generic features which should be included in all such packages to facilitate the 'uptake' of information from a computer screen.

Implications for software and hardware designers

In the light of this chapter there are several messages for software and hardware designers. Software designers need to work much more closely with their target audiences of both children and teachers, at least in the formative evaluation phase. It would be even more beneficial to involve teachers at earlier stages, say in the specification and design phases of courseware production. Some groups, such as NESTA Futurelab, are at the forefront of such activity (Murphy 2003).

The pedagogical element of much software designed for use in primary science is frequently lacking. In Table 2.1, an evaluation of several published primary science CD-ROMs by student teachers indicated problems such as:

- content too difficult for the target age group;
- no differentiation for different ability levels;
- not enough pupil interaction possible;
- poor assessment elements, for example no 'second chance' facility;
- no explanation of experimental results.

These problems can be addressed by more consultation with pedagogical experts in the area and more evaluation by the target groups at each stage in the production. The author of this chapter suggests a set of generic pedagogical issues which developers, in consultation with subject matter experts, should address in all courseware:

1. Is the software (e.g. a CD-ROM) an appropriate delivery medium for the particular content or skill area being addressed?
2. Is the pedagogical approach (e.g. branched tutorial) the most appropriate to enhance learning of the material?
3. Has the navigation been fully piloted and evaluated by the target group?
4. Is the terminology appropriate for the target group – is there a hyperscript facility and is it sufficient?

5. Has the material been checked for bias towards any particular group of users?
6. If the package is intended for class use, has differentiation in pupil ability levels been addressed?
7. Have the developers made provision for pupils with special educational needs?
8. Are there measurable learning outcomes (if appropriate)?
9. Have the developers taken expert advice about an appropriate assessment strategy for the target group?
10. Are learners sufficiently motivated by this package?
11. Is there a voice-over? How does it contribute to the learning intentions? Might the accent distract learners?
12. Are interactions fairly frequent and meaningful? Do longer periods of working with this package render the interactions repetitive and menial?
13. Are the graphics pleasing?
14. Do the graphics distract the user in any way?
15. Are there directions and are they clear?
16. Is the lesson length satisfactory?
17. Does the pupil fully determine the pace of learning?
18. Is there inclusion of a book marking facility (where appropriate)?

In the case of software designed specifically for primary science, developers should also ensure that courseware design addresses the aims of primary science.

The implications for hardware developers highlighted in this chapter are many. Though there are good examples, in general data loggers must be far more robust for use in both primary and post-primary schools. Remote data loggers would be ideal, particularly if they could be reliable in providing replicable data. Too often the present generation of data loggers, in the experience of this author, have been found wanting in this regard. The digital microscope has been a welcome and potentially valuable tool for use in the primary classroom. Unfortunately, whilst the technical aspects were very carefully addressed in its development, the pedagogical issues associated with how teachers and pupils can maximise its potential for use in primary science were neglected. Consequently, it is this author's experience that there is widespread under-use of this equipment in primary schools (Murphy 2003).

In an ideal world I would also like to see custom-made computer hardware in primary classrooms. I am sure that there is a huge market for lighter, more mobile machines with infra-red connections which are designed for use specifically by children in classrooms. Current machines are, by and large, designed for adults who work in offices. I would also advocate that developers of such machines lobby for 'school' as opposed to 'office' software to be installed. Children's books, desks and microscopes, are specifically designed to enhance their learning environment – why not computers? The situation is slowly moving forward, but it is as yet far from ideal.

References

Ausubel, D.P. (1968) *Educational Psychology: A Cognitive View*. New York: Holt, Reinhart and Winston.

Ball, S. (2003) 'ICT that works', *Primary Science Review*, 76: 11–13.

Becta (2002) *Using Web-Based Sources in Primary Science*. Coventry: Becta.

Cockerham, S. (ed.) (2001) *Internet Science*. Hemel Hempstead: KCP Publications.

Department for Education and Employment (DfEE)/Qualifications and Curriculum Authority (QCA) (1999) *Science – The National Curriculum for England: Key Stages 1–4*. Norwich: HMSO.

Department for Education in Northern Ireland (1996) *The Northern Ireland Curriculum*. Belfast: HMSO.

Dorman, P. (1999) 'Information technology: issues of control' in David, T. (ed.) *Teaching Young Children*. London: Paul Chapman Publishing.

Feasey, R. and Gallear, B. (2001) *Primary Science and Information Communication Technology*. Hatfield, Herts: ASE Publications.

Goswami, U. (2004) Neuroscience and education, *British Journal of Educational Psychology*, 74: 1–14.

Greenfield, S. (2000) *Brain Story*. London: BBC Books.

Greenwood, J., Beggs, J. and Murphy, C. (2002) *Hands up for Science! Report for Science Year. Northern Ireland*.

Higginbotham, B. (2003) Getting to grips with datalogging, *Primary Science Review*, 76: 9–10.

Lias, S. and Thomas, C. (2003) 'Using digital photographs to improve learning in science', *Primary Science Review*, 76: 17–19.

McFarlane, A. (2000a) The impact of education technology, in Warwick, P. and Sparks Linfield, R. (eds) *Science 3–13: The Past, The Present and Possible Futures*. London: Routledge Falmer.

McFarlane, A. (2000b) *Information Technology and Authentic Learning: Realising the Potential of Computers in the Primary Classroom*. London: Routledge Falmer.

McFarlane, A., Friedler, Y., Warwick, P. and Chaplain, C. (1995) 'Developing an understanding of the meaning of line graphs in primary science investigations, using portable computers and data logging software', *Journal of Computers in Mathematics and Science Teaching*, 14 (4): 461–480.

McFarlane, A. and Sakellariou, S. (2002) 'The role of ICT in science education', *Cambridge Journal of Education*, 32 (2): 219–232.

Murphy, C. (2001) 'Environmental education 2020', in Gardner, J. and Leitch, R. (eds) *Education 2020: A Millenium Vision*. Belfast: Blackstaff Press.

Murphy, C. (2003) 'Literature review in ICT and primary science. A report for NESTA Futurelab'. Bristol: NESTA Futurelab Series.

Murphy, C. and Beggs, J. (2003) 'Primary pupils' and teachers' use of computers at home and school', *British Journal of Educational Technology*, 34 (1): 79–83.

Murphy, C., Beggs, J. and Carlisle, K. (2005) 'Computer conferencing in coteaching; paper presented at the August 2005 European Science Education Research Conference in Barcelona, Spain.

O'Connor, L. (2003) 'ICT and primary science: learning "with" or learning "from"?' *Primary Science Review*, 76: 14–17.

Osborne, J., Ratcliffe, M., Collins, S., Millar, R. and Duschl, R. (2001) *What Should We Teach about Science? A Delphi Study*. London: King's College.

Poole, P. (2000) 'Information and communications technology in science education: a long gestation', in Sears, J. and Sorenson, P. (eds) *Issues in Science Teaching*. London: Routledge Falmer.

Scottish Office Education Department (1993) *Environmental Studies 5–14 National Guidelines*. Edinburgh: SOED.

Teacher Training Agency (2003) *ITT Exemplification Materials: Using ICT in Primary Science. Using Information and Communications Technology to Meet Teaching Objectives in Primary Science*. London: TTA.

Vygotsky, L. (1978) *Mind in Society*. Cambridge, MA: Harvard University Press.

3

POSSIBILITIES AND PRACTICALITIES: PLANNING, TEACHING, AND LEARNING SCIENCE WITH ICT

John Williams and Nick Easingwood

Introduction

In 2004 an article in *Biobits* (the newsletter of the Institute of Biology, Issue 3) suggested that there had been a decline in the amount of practical science taught in secondary schools. Whilst the evidence was mostly circumstantial, two reasons given for this apparent decline were health and safety regulations and a shortage of equipment. In responding, Dr Ian Gibson, the Chair of the House of Commons Select Committee for Science and Technology, questioned whether such a decline was actually taking place and, if it was, whether these were indeed the reasons. He wondered if the problem was perceptual rather than actual.

Although Dr Gibson was referring to secondary school science, we have found that in many English primary schools the amount of practical science taught does seem to have decreased in recent years and, in consequence, the use of much relevant ICT. These are personal observations on our part, and it is difficult to suggest reasons for this without more systematic evidence. Safety issues may play a part, in that even a small amount of disruptive behaviour during practical lessons (and if we are honest we have all suffered that at some time in our teaching career) can be a problem. However, there is no need to use dangerous chemicals or equipment in primary science. Indeed, the authors have found that practical science will interest, motivate and engage primary school children, including those with special needs. Our experience suggests that the factors in this decline in practical work are more likely to be the demands of the literacy and numeracy strategies, the all-pervading demands of formal assessments and the amount of planning that is now required from all teachers. Nevertheless, there are schools and individual teachers within schools who manage to include practical science in their curriculum. We have even visited schools in England that have decided to dispense with such things as the QCA Schemes of Work and return to a limited topic-based curriculum that includes extensive, practically based scientific enquiry.

In this chapter we suggest why it is important for primary science to provide a practical basis for classroom discussion, collaboration and learning, and we consider how and when ICT can be used both to enhance its content and to record its findings. We include examples of what we think are appropriate science topics so as to establish what skills are needed, by the teacher as well as the children. We will constantly have in mind that it is science that is being taught and that ICT, whilst being a vital element of the lesson, should be used to support the science and not dilute it or take its place altogether. We will include some practical suggestions as to how this can be accomplished within the school and classroom.

Practical science and ICT in the classroom

In our book *ICT and Primary Science* (Williams and Easingwood 2003) we have suggested two main reasons why science in the primary school should almost always be taught with reference to practical experiences:

1. **Science in the wider world is essentially practical**. It is carried out in laboratories, workshops, observatories and even in the 'field', which can be any part of the natural world from the arid desert to the depths of the oceans. Whatever the science involved it requires a set of skills that can only be learnt through practice and experience and which in turn will illuminate the body of knowledge which we call 'science'. Of course there are examples of pure theory which appear to contradict this. Yet, however imaginative these theories may be they are usually based not only on sound scientific principles but also on practical scientific activity. Darwin, for example, based his theory of evolution on his scientific observations. He was in fact a very practical scientist. We should allow children as far as possible to learn these skills, observation being perhaps the first and most basic. They are not only important in themselves, but through their use children will be more able to develop a better understanding of the essential scientific

concepts. For example, children may learn something about a simple animal such as a woodlouse by copying a picture from a book. However, they are more likely to have an understanding of how it lives, what kind of animal it is, and its place in the animal kingdom if they study it in its natural environment. If the children then collect some of these creatures to make a series of careful choice chamber tests back in the classroom, then they will be able to check the observations that they first made in the field. They may even go further and formulate and test their own hypotheses, all fully supported by various aspects of ICT which will be described later. This kind of learning simply cannot be done only with reference to the secondary material, although a CD-ROM might help in some cases! Without these practical applications teaching science would be akin to teaching art without ever touching a paintbrush, or learning music without handling an instrument or even being allowed to sing. It would also be very dull and the enthusiasm of the children would be lost, which brings us to our second point.

2. **In our experience young children are highly motivated by practical work of any kind, and even the most reluctant learners seem to enjoy it.** In the primary school, by practical science we do not only mean practical experiments, but also role play, drama, some technology, investigation and observation (as described above with the woodlice) as well as the appropriate use of ICT. When young children are first introduced to science, they are faced with abstract concepts such as life processes, electricity and forces. Surely the only way they can hope to understand such things is by practical application and study? They may well have an instinctive idea of, for example, the nature of electricity, which can be surprisingly sophisticated, but the best way for them to explore these ideas is to work with real bulbs and batteries. Life processes must surely include actually growing something, but could also involve both drama and role play when it comes to learning about such things as bacteria and their effect on the body. If it required Galileo to carry out numerous experiments whilst investigating forces (perhaps the most abstract of the three), then we would argue that children should carry out their own practical investigations of this highly abstract area of science. What we are suggesting is, of course, the notion that before an abstract idea can be fully understood it must first go through a concrete stage that can form the basis of thought, discussion and the comparing of ideas.

Science, ICT and the National Curriculum

Despite the fact that the issues that we discuss in this chapter hold true in a 'National Curriculum-free' world, it is in the context of the English National Curriculum that most of our work with teachers and children has taken place. We would therefore like to make a few key points about it here, and we will link some of our later comments to the specifics of National Curriculum documentation only where that seems appropriate.

By using National Curriculum (DfEE/QCA 1999) documentation creatively and imaginatively those teachers who believe that science is a practical subject will be able to teach it in that way. Within the National Curriculum ICT has its own section. However, there is also a separate statement at the beginning of the document emphasising its use across the whole curriculum. In the teaching requirements there is an emphasis on the links with other subjects, and in the programmes of study there are explicit guidelines which state that the computer should play an integral part in other areas of the curriculum, and particularly in science. Many schools seem to have a slot for both ICT and science in their timetables and clearly there are ICT skills that need to be learnt. However, once these are understood they should be an integral part of any science investigation. We believe strongly that it essential to integrate the ICT with the science, thus allowing the teacher to find the time for the practical science work described above.

As we have stressed, ICT should not be an 'add on' part of any subject, but should be a carefully planned and integrated area of the curriculum. In this way it will not only allow more time for the practical work, but will enhance and stimulate students' learning. ICT capability is a key feature of teaching and learning where knowledge, skills and understanding are developed in a practical and meaningful context. It is also important to remember that the practical investigation and the collection of data is as much an integral part of the ICT component as using the hardware and software.

So how should the class teacher go about integrating ICT into science?

Planning the lesson

When making any decision as to whether or not ICT should be used to support the teaching and learning of science, the teacher needs to be completely clear as to why it is being used, as well as being convinced that its use will actively enhance the teaching and learning experience. There is little point in using ICT if the intended teaching and learning outcomes could be more easily and efficiently achieved by not using the computer. We have already stated that the use of ICT should not replace the practical experience of handling scientific equipment and engaging in genuine scientific investigation and discovery. There is also a 'value added' component to this aspect – there is little point in using £1,000 worth of ICT hardware and software to make a teaching point that could just as easily be achieved with a set of plastic beakers costing 10 pence.

So what clear advantages can the use of ICT bring to the teaching and learning of primary science? First, quite apart from being a great motivator, there is the ability of ICT to act as a means to encourage and facilitate collaborative and active learning. A very powerful feature of the computer is that it can act as a focus for group work, where raw data is transformed into information through the use of graphs, tables and charts, or where the reports of scientific investigation can be created and presented, perhaps by the use of presentation software incorporating still and video digital imaging, text, sound and animations. The capacity, speed, range and automatic function of a computer enables large amounts of different kinds of data and/or information to be handled quickly, automatically and in an integrated way. It enables the removal of the 'manual' element from work, so pupils can access higher levels of intellectual engagement and learning. For example, rather than spending a significant proportion of the lesson drawing and colouring in histograms, the computer can produce these charts for the pupils, thus enabling them to spend the time saved in engaging in the higher-order scientific thinking skills of reflection and analysis. It is the computer's ability to act as a word processor, desk-top publisher, database or spreadsheet, as well as acting as a vehicle for the Internet and e-mail, that gives it its pedagogical power and potential. Additionally, when used for more specialised scientific applications, such as data logging and control technology, it can truly provide opportunities for primary age pupils that would have hitherto been impossible. And where laptops, personal digital assistants (PDAs) or handheld data loggers are used, ICT is no longer confined to the classroom or the specialist science lab. The pupils can take these 'real' pieces of hardware outside into the real world and can use them in a realistic and meaningful context. Indeed, within the school grounds, they may be able to access the Internet through the use of a radio network, giving them ready and immediate access to a whole range of online opportunities, from researching key scientific concepts, ideas and knowledge, to e-mailing experts in universities or museums 'on the spot'.

So, bearing the above in mind, what, as teachers, do we need to consider when we plan any science lesson where ICT is to be used? What are the key features of an effective lesson?

Above all, the lesson should be interactive. Active learning is a crucial part of any lesson, but particularly in ICT and science. The pupils must interact with the computer in that they should not be passive recipients of the data or information on the screen. They must be in control of the computer, not the other way round. Additionally, it is critically important that the teacher should interact with the pupils and the computer. It is when the teacher intervenes by asking key questions that pupil learning is greatly extended. The questions asked need to be sufficiently focused to ensure that the pupil thinks carefully about the concepts being taught, but also sufficiently open-ended to ensure that considerably more than a simple yes/no answer is required. This will invariably mean questions of a ‘what if?’ ‘why?’ ‘how?’ nature. Example questions might include:

- What would happen if the variables in this spreadsheet were changed?
- Why do you think that the crosses on the scattergram are clustered together? What is this telling you?
- How might the variables in the spreadsheet be changed?

This demonstrates clearly that computers can never replace teachers! In fact, their role becomes absolutely crucial to the success of the lesson. It is teacher’s ability to provide the detailed subject and pedagogical knowledge and the ability to ask the right question at an appropriate moment that makes the use of ICT such a powerful tool for the teaching and learning of science. It is these abilities that the teacher needs to utilise in order to ensure that the pupils are interested and on task in such a way that both their ICT and scientific capabilities will fully develop.

Quite apart from extending pupil learning, this kind of questioning is an extremely powerful means of assessing pupils through formative assessment, or assessment for learning (AfL). This provides the opportunity to assess pupil progress in line with the stated objectives for that particular lesson. Clearly, assessment must be planned for at the appropriate stage and must reflect the intended learning outcomes of the lesson. In this way, pupil progress can be ascertained qualitatively. Indeed, through this constructivist, questioning method, many of the pupils, even the youngest ones, will be able to engage in self-assessment – and record their thoughts and findings.

This may prove to be very useful, as assessing ICT is a potentially difficult area. What exactly is it being assessed – the use of the technology, the technology itself, or the context in which it is being used? We have already seen that as far as primary school ICT is concerned, it is in fact all three, as we are seeking to develop ICT capability – the knowledge, skills and understanding underpinning its use. However, in the primary school, if ICT is invariably and quite rightly taught through the context of another subject – in this case science – then the question of ‘appropriate’ assessment is brought into sharp focus. Thus the key objectives for the lesson will be scientific ones, with perhaps a secondary objective concerning the use of ICT. Indeed, the National Curriculum document for ICT makes it quite clear that there is an expectation that ICT capability will be developed in this way.

Although there are many programs available to children, we should take care not to assume that by their use alone children are learning science. Some databases will allow children to produce graphs, pie charts and tables from an already selected range of data. Whilst these are fine for children to use to familiarise themselves with the programs and the computer, once this has been accomplished, surely it is better for them to use their own data collected during one of their own science investigations? If they use their own statistics this may also provide more time for further work. When planning what kind of program to use, teachers need also to be aware of exactly what they want the children to learn. The authors recall that when ICT was first introduced into schools, there were many programs (and they still exist) that showed various circuits with bulbs and batteries, which required the users (the children) to decide whether the bulb would light or not. Whilst this might perhaps be a useful reinforcement exercise, we do not think it can take the place of actual 'hands on' experience. Children will enjoy manipulating the wire and looking closely at a bulb to see what is inside it, and we have found that even teachers can discover what happens when a 6-volt battery is used together with bulbs which are labelled 1.5 volts!

CD-ROMs are another aspect of ICT which need to be used with care. Obviously when studying certain areas of science it is just not possible to learn in an entirely practical way. For example, there are parts of work on life processes and living things that require children to learn about the human blood system. Elements of work on the Earth and Beyond also reveal some constraints on the use of practical enquiry! A user-friendly, interactive animated CD-ROM can be invaluable for these, although in their planning teachers need to make sure – perhaps by producing clear and simple guidance sheets – that their pupils know what to look for when using a CD-ROM. These can include specific questions for the children to answer, so that the teacher will know that they have understood what they have been watching. At another level it will help the children not be distracted by other parts of the program. We well remember watching children using this kind of CD-ROM, who without these guides had become more interested in the reproductive system rather than the skeleton which is what they had been asked to study. We did not want to stifle their curiosity, but it just was not part of the day's project!

Although there are other aspects of ICT that should be used whenever possible, such as the digital microscope (a 'must' and not just for life processes), the digital camera and of course simply using the computer as a word processor, it is in the storage and utilisation of scientific data that the computer comes into its own. A computer is able to store vast amounts of data, in many different forms, and at great speed. For this the children will use database, spreadsheet and data-logging programs. These can come in various forms and it will be helpful if we remind ourselves just what they are designed to do, and how they can be used in the classroom.

Database programs

A database program allows for the storage of considerable amounts of information, which can subsequently be retrieved, sorted and researched, and be produced at a later stage in a variety of graphical or tabular forms. We think that there are three basic kinds of database that can be used in the primary school.

Free text database

This is used to search for information on the World Wide Web or on a CD-ROM. The children will simply use the 'search' function of the web page or the appropriate software to find specific information. This could be anything from the habits of a particular kind of animal to the details of a painting in an art gallery.

Branching database

This asks the children to describe an object so that it can be identified by answering a sequence of simple questions. The database may already be set up for the pupil to follow and may be specially written to identify any number of different things from insects to rock types. Of more interest, however, are the blank databases. The structure of the database is provided for the children so that all they need to do is to fill in the necessary questions that will eventually lead to the identification of their chosen object. It is important that these questions must allow for a simple 'yes' or 'no' answer. This, at first, may be quite difficult for the children to manage. They will, we hope, be used to answering questions of the 'what if? or 'why do you think?' type. To actually be required to formulate questions of their own which must only have a binary answer, particularly when they might equate 'no' with 'wrong', is quite a challenge. However, it is an imaginative one, and a considerable learning process in itself. Once completed, this database can form a part of the school's science resources.

Random access database

Arguably the most useful of the three, this will also be the most familiar to teachers, although it may only have been used for very simple topics such as those based on hair and eye colours. Although there are several database packages available for primary schools, most use the same basic structure. A whole topic, such as 'birds', will form a file and is saved in the same way as any other program application file. An individual object within the file is referred to as a 'record', and will contain specific information about that object – in this example it will be details about the bird. Each item of information on the record is contained in a field, a further category of information under which the original birds can be sorted, which might be by type of nest or their special habitat.

If the children are to use their own information gathered during their science work then they will obviously need practice with this kind of

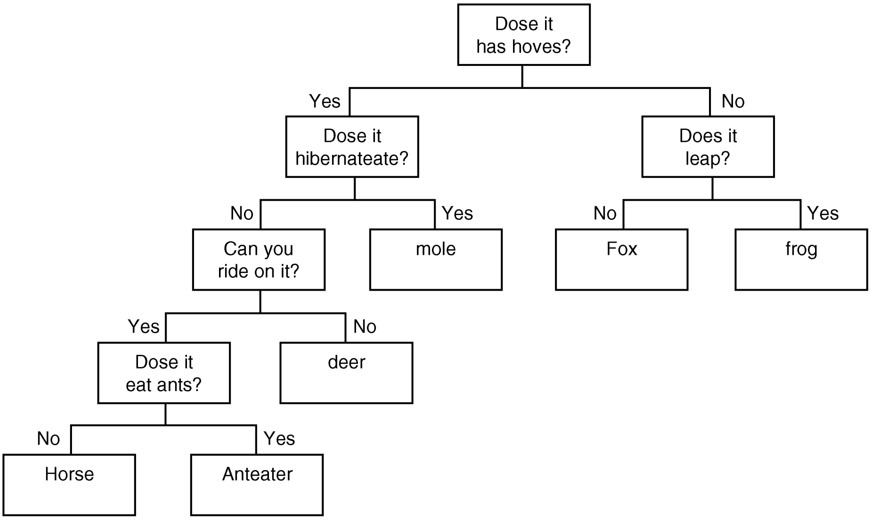


Figure 3.1 An example of a branching database, taken from a case study used in *ICT and Primary Science* (Williams and Easingwood 2003).

database. There are several that have been designed specially for primary schools such as 'First Workshop' and 'Information Workshop' (produced by Granada Learning) that can be used with a minimum amount of adult help. These programs contain 'ready made' databases at three different levels of difficulty, which can enable the children to find out how they work, and what they do. Nevertheless, before the children start using their own information the teacher will need to see that the information gathered during the practical work will be appropriate to the database, so that the children can become familiar with and understand the meaning of the various entries, i.e. 'file name', 'field' and 'record'. It is often a good idea for the children to keep a record of their discoveries, not as long handwritten texts but in short note format and under headings such as 'habitat' or 'feeding habits' (we are still using our example of the bird topic). These will become the fields or records, and the data can be entered directly into the computer.

Constructing the database, as important as this may be, is but half the picture. Once the database is complete the children can ask it to list the animals under different headings depending on the fields used. Birds could be listed under habitats or geographical areas, under their feeding habits or whether they are predators, carnivores or herbivores. Moreover, where relevant, this information can be displayed and printed out in a graphical or tabulated format. This complete activity allows the children to use the higher-order scientific skills of data collection, preparing and entering the data into the program, together with the subsequent computer activities of sorting, searching and retrieval.

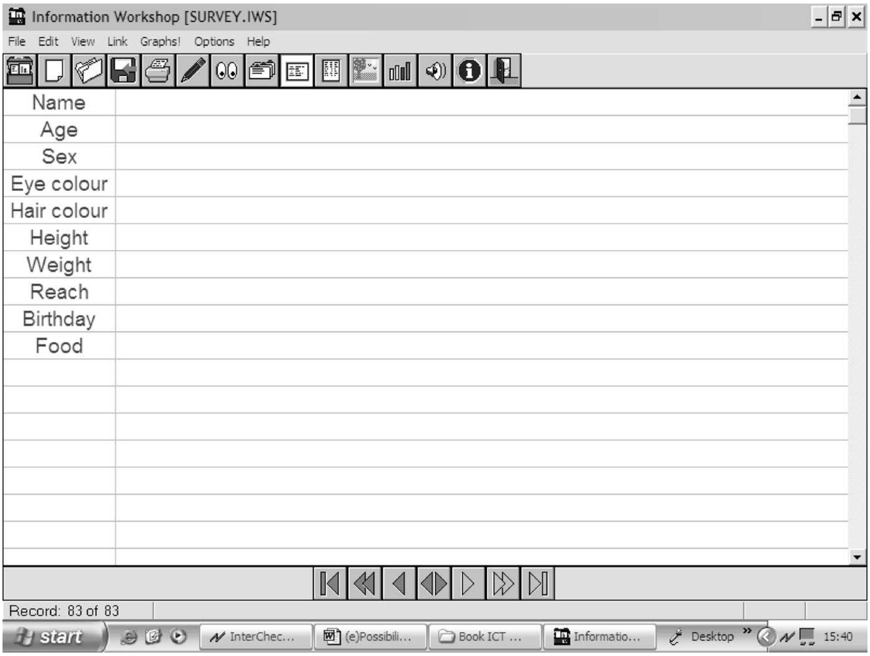


Figure 3.2 A blank database showing the fields in Information Workshop.

Spreadsheets

At first sight it might be difficult to decide when it would be more appropriate to use a spreadsheet rather than a database. As we have seen, the latter are good for collecting and manipulating data, and to a certain extent a spreadsheet can also do this. However, it will also allow the user to change the data, to make calculations with it – such as finding an average – and can utilise the given data to produce further information, such as a trend or an estimated outcome (Feasey and Gallear 2001).

To look at a blank spreadsheet on the screen is to see a simple blank table, the kind that children have often produced on paper to be filled in later with the results of their experiments. Indeed this blank spreadsheet can be used for such a purpose. However, if an average of these results needs to be entered in a subsequent column, then using the appropriate formula the spreadsheet will do this for you. (No doubt some will argue that this does not 'teach' averages. We agree that it does not teach children how to calculate them, but it does help to show children what they are and therefore what they mean by providing a real context for their use.)

As an introduction to the spreadsheet, teachers could use some of the ready-prepared ones that are available, for example those in the Black Cat Suite Number Box. Although some of these pre-prepared spreadsheets are more strictly mathematical, some are based on science topics such as ‘Pulse Rates’ or ‘Growing a Plant’. These could be used for practice, but, as we have suggested, they would have more meaning for children if the information came from their own projects.

Once the children have become conversant with these the teacher can introduce them to a whole-screen blank spreadsheet. The children would fill in each space or cell with names, measurements or numbers, depending on what is needed for the topic. As we have already suggested, one of these columns could be the average of several measurements. This can be obtained by highlighting the name and average columns from the original spreadsheet, which can be done by holding down the ‘CTRL’ key and clicking and dragging in the usual way.

We have often found that as children use these sheets for recording their findings they soon learn how to fill the ‘cells’ and how to alter their size and format. As they become more confident in their use the children are able to use the information displayed before them as a starting point for discussion and even take note of any trends and relationships that appear in the data itself.

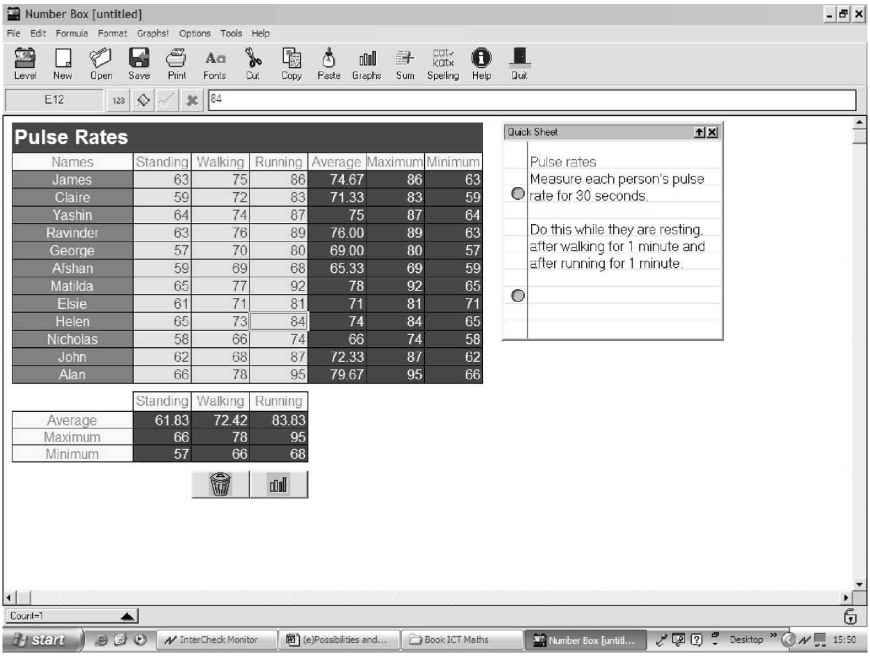
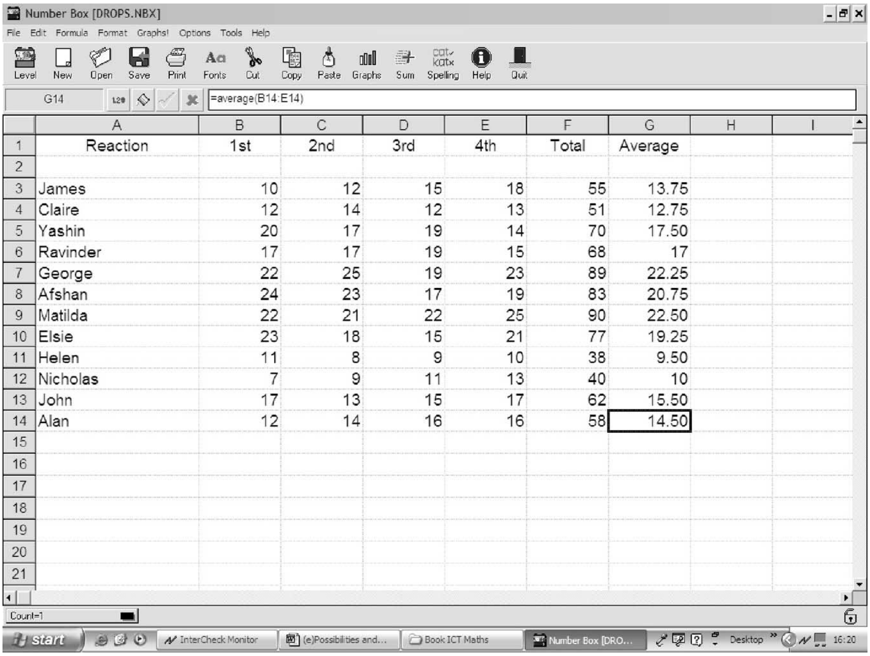


Figure 3.3 Pulse rates spreadsheet in Number Box.



	A	B	C	D	E	F	G	H	I
1	Reaction	1st	2nd	3rd	4th	Total	Average		
2									
3	James	10	12	15	18	55	13.75		
4	Claire	12	14	12	13	51	12.75		
5	Yashin	20	17	19	14	70	17.50		
6	Ravinder	17	17	19	15	68	17		
7	George	22	25	19	23	89	22.25		
8	Afshan	24	23	17	19	83	20.75		
9	Matilda	22	21	22	25	90	22.50		
10	Elsie	23	18	15	21	77	19.25		
11	Helen	11	8	9	10	38	9.50		
12	Nicholas	7	9	11	13	40	10		
13	John	17	13	15	17	62	15.50		
14	Alan	12	14	16	16	58	14.50		
15									
16									
17									
18									
19									
20									
21									

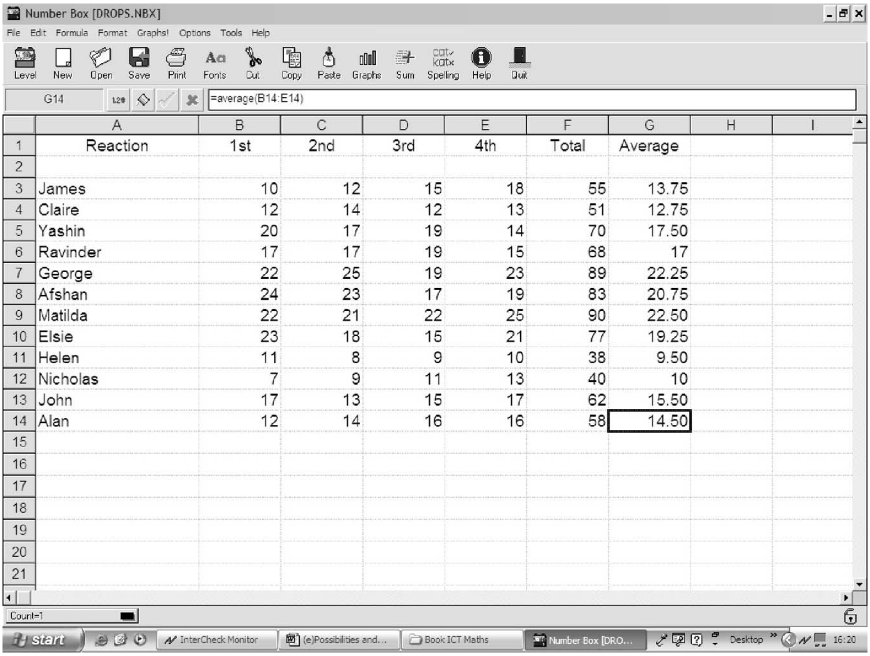
Figure 3.4 Number Box spreadsheet used to record dropping the ruler as part of a topic on 'Reaction Time'.

Data logging

As we have seen in the previous chapters this allows for the collection, collation and displaying of data, gathered directly from the environment or workbench, through the help of special electronic sensors attached to the computer. Although there are several different sensors available, those which log temperature, light and sound are the most commonly used in the primary school. There are several advantages in using a program of this sort for most primary science projects. One obvious advantage is that it saves that most valuable commodity – time! For long-term investigations such measuring light, temperature and sound changes in the classroom or an outside habitat over a period of a day or more, once the sensors are in place the children do not have to stand and watch. They can just go away whilst the sensors and computers do this work for them. The children can carry on with something else, ideally related to their science investigation. Of course they will eventually need to study the results and recordings, but that is when the science learning takes place. It is this reflection on and the analysis of the data displayed that is of fundamental importance.

Another advantage of using data logging in primary science is that it provides an instant but long-term visual representation of 'what is going on' in either a macro or micro environment (Porter and Harwood 2000). The children can use more than one sensor at a time, so if they needed to find out temperatures, light intensities or sound levels all at once this could be done and the information displayed for further investigation.

It is not difficult to imagine the many science projects in which data-logging equipment could be used. One such piece of equipment is the Ecolog system, produced by Data Harvest. This consists of a small interface box (to connect with the computer), leads and the software. There is also a manual which suggests many possible uses for the equipment. Data Harvest and other manufacturers are continually updating their products, both hardware and software.



	A	B	C	D	E	F	G
1	Reaction	1st	2nd	3rd	4th	Total	Average
2							
3	James	10	12	15	18	55	13.75
4	Claire	12	14	12	13	51	12.75
5	Yashin	20	17	19	14	70	17.50
6	Ravinder	17	17	19	15	68	17
7	George	22	25	19	23	89	22.25
8	Afshan	24	23	17	19	83	20.75
9	Matilda	22	21	22	25	90	22.50
10	Elsie	23	18	15	21	77	19.25
11	Helen	11	8	9	10	38	9.50
12	Nicholas	7	9	11	13	40	10
13	John	17	13	15	17	62	15.50
14	Alan	12	14	16	16	58	14.50

Figure 3.5 A typical sample of the graphical information obtained from sensors during a data-logging project (reproduced by kind permission of Data Harvest Limited).

Widening the use of applications for primary science

Obviously not all science – primary or otherwise – needs to have a computer input. There was much good science done in primary schools before computers became widely available. However, we hope that we have made clear the advantages of some specific uses of ICT. These can be for logistical purposes (that is, saving time by removing many of the time-consuming repetitive tasks) or as an essential part of the recording of science, or even as an aid to the understanding of the science learning process itself. Once the teacher has decided on and planned a topic then it should become clear which of the types of programs will be needed.

If, for example a topic such as 'mini-beasts' is to be studied then databases will be invaluable. It is hoped that the children will be studying a variety of habitats so that not only will they be able to observe and identify different types of animals, they will also be able to make comparisons between where and how these animals live, what food they might require and what environmental conditions they prefer. All these observations can be entered into a suitable database. When the information has been collated, analysed and displayed in a relevant format then the resulting discussions might lead the children to answer the important 'why' questions. These should, where possible, always follow the 'what is there, what can you see, what have you found?' type of enquiry so that evidence forms the basis of discussion.

So far most of our examples have shown the use of ICT in biological science projects. Indeed, we have used such examples in our book *ICT and Primary Science* (Williams and Easingwood 2003) to show in detail how all these programs can be used in one single ecological project carried out by Year 6 children. This is not to suggest that other areas cannot benefit. Databases and data logging may appear to lend themselves specifically to the natural history aspect of the curriculum but this need not always be the case. Any information gathered during a project on materials, particularly if the work is related to the grouping of materials, can easily be collected and used on a database, whilst the sensors of a data logging program immediately lend themselves to light and sound or to a topic involving traffic surveys and noise pollution. Spreadsheets, as our pictures show, are very definitely structured so that they can be invaluable for any of the sciences.

An example of how all these programs could be used for one topic

For this section we will use as an example a topic on 'Forces'. At Key Stage 2 this involves motion, types of force, friction and the measurement of force. In our view all this might be taught as one topic, which is perhaps better than only considering one example, such as only teaching about gravity. Without ‘forces’ we could not move, aeroplanes could not fly, ships would not float, indeed it is ‘forces’ that keep our solar system in place. Surely this is what we need to teach? Perhaps not all at once, but within such an all-embracing topic several conceptually linked activities can provide the focus for the work. We could use the children’s own footwear to show the importance of friction when walking as well as to measure friction by pulling the shoes over different surfaces with a spring balance. By utilising the children’s first-hand experiences we can find out which of the shoes best resists the pull; is it the one with the most tread? We can also experiment with a simple paper dart to show the four forces involved in flight – thrust, drag, lift and gravity. We can return to the experiments on floating and sinking first carried out at Key Stage 1 to show that given the right surface area anything will float if the force of gravity can be overcome by the upward ‘thrust’ of the water. By allowing children to attach magnets to model cars they will soon discover that magnets push as well as pull and need not even touch each other. Finally, children can replicate Galileo’s experiments with gravity and motion and learn some history of science as part of the process towards the ultimate goal of scientific literacy.

Can all the computer programs we have described be utilised for this topic? As we shall see, databases and spreadsheets certainly can, but data logging – at first sight at least – may seem to be out of place here. We certainly do not advocate any contrived situation, invented just as an excuse to introduce various aspects of ICT for their own sakes. However, there are aspects of data logging that are not only appropriate but will add a completely new dimension to this experimental work. We are helped here by the work of Galileo and Newton who first gave us a consistent view of the dynamics of movement, both for the universe as a whole and here on the Earth. Galileo’s experiments are often to be found in the primary classroom, although usually in a different context. We have seen children running model cars down an incline fitted with different surfaces to discover if a rougher surface affects the distance travelled by the car. This gives a good indication of the force of friction, although there is seldom any indication as to how this might connect with other forces or to the science of motion, or indeed even to Galileo. The children will often measure just how far the cars travel and note how friction can affect this distance. This is good, but for this work teachers need to understand that when Galileo studied what he called ‘local motion’ he was studying the way different objects moved through the force of gravity. He at first studied them as they fell freely to Earth, but because this was unsatisfactory from an experimental point of view (it was too quick) he later constructed an incline plane. The original of this is in the History of Science Museum in Florence. The most striking thing about this construction, apart from the fact that Galileo actually used it, are the little bells placed at intervals down the ramp. A ball was rolled down and in order to make careful measurements of its speed, the ball rang the bells on its way down. By noting the time between each strike, Galileo was able to describe mathematically the way objects behave under freefall, their accelerated motion as well as their constant speed, or, as it is now called, the inertial motion.

We are not for one moment suggesting that primary children need study this in any detail, but as they do use ramps and toy cars as just described then why not give them some of the background and actually make some accurate measurements? Several manufacturers produce 'light gates' (a series of light-sensitive cells) for use with data loggers and these can be used as accurate timers. There is a light gate at the top of a ramp which is activated by the model car to start the timing and one at the bottom to stop it. The slope of the ramp can be altered and times compared. This seems to be an ideal way of utilising data-logging technology and using ICT to record the results and to look for patterns.

Any enquiry to show the effect of magnetic force, such as the strength of a magnet using measurements of the distance of the attractive force, can be entered onto a spreadsheet, as can work on the measuring of friction, such as those mentioned earlier using the children's own shoes.

As we have seen, databases (or at least random access databases) tend to lend themselves to such things as population studies, be they biological or geographical. However, why not, in the database suggested for the materials project, include a field for magnetic attraction? There could also be one for electrical conductivity, for as we know certain metals – whilst they are good conductors of electricity – are not magnetic. As with all these examples, when making this entry into a database we should bear in mind the requirement to develop children's understanding of scientific enquiry. For example, they will be able to use their collected data to assess evidence, search for patterns within that evidence, and compare and contrast it with previous information. Finally, they will be able to communicate their findings clearly and simply.

There is no reason why, in any science topic, we should not take advantage of other aspects of ICT. Digital video, or at least still digital images of the children's experiments, could be a part of their record of work. Word processing, desk-top publishing or presentation software could be used so that the children can explain, when necessary, what they have done. This could incorporate still or moving images, sound and text, and these in turn could be subsequently displayed in a variety of forms, including on the World Wide Beb. Simple design programs, or even simple pictures from various programs now in common use, can help to explain various ideas and concepts such as those forces described earlier.

There may also be some particular aspects of science at Key Stages 1 and 2 that for the moment do not lend themselves to practical work, although we do not think there are many. These could include the so-called 'minds on' activities (Watt 1999) as distinct from the 'hands on' activities of practical science, which lend themselves to the appropriate use of ICT. We have, in another context, suggested that constructing food chains could be such an activity, where a simple design program would help to guide and later illustrate the children's thinking.

Some final thoughts

We hope that we have shown here, even putting aside the requirements of the National Curriculum, that science in the primary school should be largely practically based and that ICT must be an integral part of the work. ICT can be used at different times during a scientific enquiry – it can be used for research, collecting data, analysing information, recording findings and displaying and presenting the results of the scientific investigation. Time can be found for both within even today's crowded syllabus. The new National Primary Strategy (DfES 2003) gives us the opportunity, for within it you will find the phrase 'empowering primary schools to take control of their curriculum and to be more innovative and to develop their own character'.

References

Department for Education and Employment (DfEE)/Qualifications and Curriculum Authority (QCA) (1999) *Science – The National Curriculum for England: Key Stages 1–4*. Norwich: HMSO.

Department for Education and Skills (2003) *Excellence and Enjoyment: A Strategy for Primary Schools*. London: HMSO.

Feasey, R. and Gallear, B. (2001) *Primary Science and Information and Communication Technology*. Hatfield: The Association for Science Education.

Institute of Biology (2004) *Biobits*, 3. London: Institute of Biology.

Porter, J. and Harwood, P. (2000) *Data Logging and Data Handling in Primary Science: MAPE Focus on Science*. MAPE, Newman College.

Watt, D. (1999) Science: learning to explain how the world works, in Riley, J. and Prentice, R. (eds) *The Curriculum for 7–11 Year Olds*. London: Paul Chapman.

Williams, J. and Easingwood, N. (2003) *ICT and Primary Science*. London: Routledge Falmer.

4

MAKING SCIENCE INCLUSIVE: EXTENDING THE BOUNDARIES THROUGH ICT

Derek Bell and Adrian Fenton

In writing this chapter we are faced with a dilemma. On the one hand there should be no need for a separate chapter on making science inclusive through the use of ICT. This is because, almost by definition, the whole of this book is about making science more accessible for all the pupils we teach. Each chapter demonstrates ways in which ICT offers all of us established and new opportunities for extending the boundaries of our teaching and of our pupils' learning.

On the other hand, we know that all too often, when faced with particular types of pupils, we find our teaching has to go beyond our 'natural boundaries' in order to engage them. In other words, we are challenged to put our understanding of teaching and learning to the test in our efforts to help all pupils make progress. However, despite the wealth of research and curriculum resources that are available to support science, ICT and inclusion, these three issues are all too often dealt with in isolation. Murphy (2003), for example, highlights the separation of these areas and the comparative lack of research into how, when, how much and how often ICT can be used to enhance the understanding of science held by specific groups of children. Similarly, in their review of science education and ICT (which has a more secondary focus) Osborne and Hennessy (2003) only make passing reference to the benefit to 'low ability' pupils when they argue:

> the use of ICT changes the relative emphasis of scientific skills and thinking: for example, by diminishing the mechanical aspects of collecting data and plotting graphs – particularly beneficial for low ability pupils – while enhancing the use of graphs for interpreting data, spending more time on observation and focused discussion, and developing investigative and analytical skills.
>
> (Osborne and Henessey 2003: 23)

Both of these excellent reviews simply reflect that there is very little consideration of how science, ICT and inclusion can be brought together in order to enhance our practice. In this chapter we aim to redress the balance.

ICT and science can be a very powerful combination in supporting inclusion in the primary classroom if we bring them together in appropriate ways. Although Wall (2001) provides effective insights, with specific examples, of how this might be achieved for pupils from 5 to 16, we can envisage a more general model of the situation in terms of a dynamic Venn diagram, in which the extent of overlap of the circles reflects the degree to which the three elements combine to support each other. Figure 4.1 attempts to illustrate what we mean, by showing just three of an almost

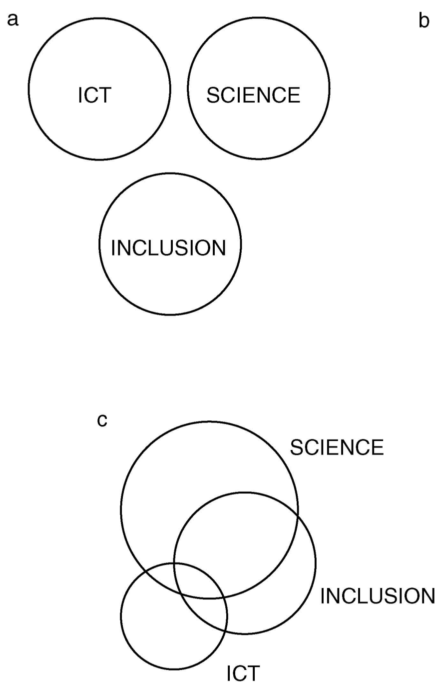


Figure 4.1 Primary science, inclusion and ICT: a model of interactions.

infinite number of possible combinations. The first (4.1a) shows the extreme situation in which ICT, science and inclusion are considered virtually in isolation, with any overlap being purely coincidental. The second (4.1b) illustrates a planned and balanced approach, bringing the three elements together in order to capitalise on ways in which they can be mutually supportive. The third (4.1c) illustration indicates one way in which, in a specific situation, there might be a particular emphasis that has been planned to meet the needs of either an individual or group of pupils. In this last example, the focus would be on the science, hence the larger circle, but with ICT supporting an aspect of the work in order to make the activity more inclusive.

The important point behind the model is that inclusion is a central principle in all our teaching. Science is a discipline which makes a major contribution to the education of all our pupils and, in this situation, the use of ICT is a vehicle for extending the learning opportunities for pupils. We should remember that, while inclusion is a principle which should underpin virtually everything we do, there will be occasions when teaching science does not require the use of ICT and conversely times when we will use ICT for other purposes. Hence it is unlikely that the three circles in Figure 4.1 will ever fully overlap.

In what follows, we will outline what we mean by inclusion in the context of this chapter, what science has to offer and how the use of ICT might be exploited to enhance the learning experiences of different pupils. We will go on to explore in more detail some of the ways in which we can develop our own teaching approaches to maximise the benefits of the opportunities made possible through using ICT. Vignettes of actual classroom activities will be used to illustrate how the principles we highlight can be put into practice. More specific examples and case studies of the ways in which ICT has been used to support science and inclusion can be found on a wide range of websites, some of which are listed at the end of this chapter.[1] We hope that, after reading this chapter, you will be able to recognise and justify ways in which the array of ideas discussed elsewhere in this book can contribute to making science even more inclusive by extending the boundaries of teaching and learning through the use of ICT.

What do we mean by inclusion?

The meaning of the term 'inclusion' is not a simple matter of providing a definition. Rather, as discussed by many authors (Farrell 2001; Lindsay 2003; Wedell 2005), it is a complex set of ideas. At the heart of the concept is the aim to ensure that all pupils, regardless of their background, culture, ethnic origin, gender, physical abilities or learning capabilities have the opportunity to engage proactively in their education. Inclusion thus involves social, political and cultural issues, as well as matters relating to teaching and learning. In writing this chapter we have focused very deliberately on the latter, with a particular emphasis on exploring ways in which ICT can be used to support children with learning difficulties and how it can overcome some of the barriers to their learning. We would agree with Rose (2002) in arguing that 'there is a need to move the inclusion debate forward through a consideration of classroom practice to address the needs of all pupils including those identified as having special educational needs'.

Furthermore, in taking this stance, we feel strongly that, as discussed elsewhere (i.e. Bell 2002, 2003; Davies and Florian 2004), making our teaching more inclusive is fundamentally an extension of our own good practice. As Davies and Florian (2004) concluded, 'questions about whether there is a separate special education pedagogy are unhelpful . . . The more important agenda is about how to develop a pedagogy that is inclusive of all learners.'

A key assumption in our approach to making science inclusive is that 'children will learn with appropriate teaching' (Solity 1995) and that 'effective teaching for those with special needs has direct relevance to effective teaching in general . . . [and] . . . a key element in teaching and learning approaches is the recognition of the learner as an active rather than a passive participant' (Wedell 2005).

Effective science teaching for children with special educational needs can take place in mainstream settings, special schools or in specific learning environments (such as a hospital school or at home). However, we should also take note of the 2002 joint statement on inclusive science by the Association for Science Education (ASE) and the National Association for Special Educational Needs (NASEN):

> Both nationally and internationally, there is a trend towards inclusion for children with special educational needs. This has been interpreted as attendance at a mainstream school for learners with special educational needs. Our view is that inclusion is not simply about placement but related to the quality of the educational experience.
>
> The current context provides challenges and opportunities to educators. Those working in a mainstream environment are engaging with a wider range of students and need appropriate support and guidance on effective inclusion and provision for the students. Some special schools are faced with the new challenge of providing an appropriate science curriculum. There exists a need for the sharing of good practice between those with different expertise.
>
> Inclusive science involves issues of access, quality, relevance and purpose. This joint statement encompasses the notion that all students with special educational needs are entitled to access high quality science education that recognises and responds to diverse learning needs.
>
> (ASE and NASEN 2002)

Although, in this chapter, we have used the phrase 'special educational needs' in line with the ASE/NASEN Statement and most of the existing literature, it is worth noting that other terminology is being introduced. For example in Scotland, the phrase 'additional support for learning' has been adopted and enshrined in legislation through the introduction of the Education (Additional Support for Learning) (Scotland) Act 2004 (HMSO 2004). Our use of the terms 'special educational needs' and 'inclusion' encompasses the ethos of providing 'additional support for learning' through the use of ICT. Examples of how ICT can help to break down barriers to learning and enrich learning have been included but other aspects of inclusion such as gender, ethnicity and social or cultural backgrounds have not been dealt with explicitly.

Our emphasis is on children with learning difficulties but we also recognise the potential for supporting pupils identified as gifted and talented, particularly in science. Work with 'gifted and talented' and 'more able' pupils is an area of inclusion that has recently been given higher recognition in the education community, encouraging schools to identify and develop their support for such students. As stated by the DfES-supported National Centre for Technology in Education (NCTE 2005), ICT plays an important role in providing opportunities for gifted students to progress at a rate that is appropriate to their abilities, accommodating their individual learning styles, whilst developing and practising higher-level thinking skills. Networks and website support for working with more able pupils have continued to develop; for example see Becta's web publication *How to Use ICT to Support Gifted and Talented Children* (Becta 2002), or the *London Gifted and Talented* web pages. ICT can be used as a vehicle to further gifted pupils' understanding through the additional supplementary activities and extension materials that are available in different software packages or web-based resources. Furthermore, 'many ICT tasks do not require the use of a specific classroom or laboratory. They can, therefore, extend learning beyond the teaching space and class contact time' (University of York Science Education Group 2002).

To further illustrate the complexity of making science inclusive, there are some students who might be gifted and talented but have other special educational needs. In these circumstances, it is necessary to explore ways in which the barriers to learning can be effectively overcome in order to engage the talents of the individual. Montgomery (2003) has considered this issue, which is referred to as 'double exceptionality', in more detail. However, as with much of this field, it is the teacher who has to tailor the learning situation to meet the needs of the pupil. Once again we are reminded of the importance of the teacher, as Osborne and Hennessy (2003) stated in their extensive review, 'we need to acknowledge the critical role played by the teacher, in creating the conditions for ICT-supported learning through selecting and evaluating appropriate technological resources, and designing, structuring and sequencing a set of learning activities.'

What does science offer?

As argued in more detail elsewhere (i.e. Bell 1999, 2002) it is widely acknowledged that learning in science provides opportunities for children with learning difficulties to develop a better understanding of the world around them, with all the possibilities and challenges that it brings. More specifically, science allows such children to (QCA 2001):

- develop an awareness of, and interest in, themselves and their immediate surroundings and environment;
- join in practical activities that link to ideas, for example, doing and thinking;
- use their senses to explore and investigate;
- develop an understanding of cause and effect.

Although written to support the National Curriculum in England, the publication *Planning, Teaching and Assessing the Curriculum for Pupils with Learning Difficulties* (QCA 2001) provides helpful material for planning learning opportunities and activities in science for pupils from 5 to 16 and includes a set of 'performance descriptions' (the p-scales) which describe stages of achievement in the early learning of children with a wide range of learning difficulties.

The contribution of science to the education of children with learning difficulties, however, goes beyond the scientific concepts and skills that might be acquired. Science also provides opportunities for children to develop self-advocacy (Mittler 1996) through, amongst other things, an understanding of choice, the development of skills and competencies, confidence in taking risks and feelings of being regarded, encouraged and supported as they develop their confidence and autonomy.

Whilst there is a wealth of material available relating to special educational needs generally and children with learning difficulties more specifically, there is little available which examines teaching and learning of children with learning difficulties in particular subject domains, and science is no exception. Yet there is some evidence which suggests that children's perceptions of their academic abilities are specific to different content areas (Carlisle 1996) and that it is not unreasonable to suggest that they may be more able to succeed academically in some content areas than in others. Thus it is important that, as teachers, we are sensitive to the response of individual pupils to science as a subject, as well as the opportunities it provides.

What can ICT in science add?

Before considering in more detail the potential of ICT to extend the boundaries of teaching and learning, we should remind ourselves that our understanding of teaching and learning should underpin the way in which we use ICT. Chapter 1 has already emphasised some of the perspectives that are important here. Harlen (2005), for example, provides support for these in her excellent account of teaching, learning and assessment in science for pupils aged between 5 and 12 years. In particular she emphasises the value of children's ideas, the importance of asking questions and dialogue, the need for developing process skills to underpin conceptual understanding and the major contribution of positive attitudes and values to learning. These underlying principles apply in all situations but, as Bell (2002) has argued, in supporting inclusion particular attention must be paid to:

- the value of being able to understand, recognise and, most importantly, make explicit the incremental steps that are required to help children develop their use of process skills and early understanding of concepts and;
- the need to adapt and modify our teaching strategies, often in small but significant ways, in order to meet the learning needs of individual and groups of children, paying particular attention to the use of language, questions and dialogue, the relevance of activities to the children and the selection of resources.

Appropriate, and we would stress *appropriate*, use of ICT in all its forms has the potential to enhance teaching and learning in science for children with special educational needs in much the same way as for other pupils. ICT can add to their motivation, develop their social interactions and improve their confidence in their work. More specifically, in relation to science it can, amongst other things, extend and enhance observations, provide records of events, improve presentation and communication of findings and support dialogue in reaching conclusions. Furthermore, we would suggest that ICT can:

- make science activities more physically accessible;
- increase the levels of engagement between pupils, teachers and the topics being studied;
- extend and develop the teaching and learning dialogue;
- facilitate the recording of evidence, reinforcement of experiences, ideas, evidence and concepts, and reporting of achievements and progress;
- develop an extended learning community through dissemination and networking.

Making science more physically accessible

For many children, ICT enables them to do things they could not otherwise achieve. Appropriate modification of ICT equipment allows pupils with physical disabilities to, for example, prepare reports to a high presentational standard, construct diagrams, make selections from option lists and use simulation software to test their ideas. This can be done through a range of devices including roller balls, joysticks, sticky keys, concept keyboards and touch screens. Specific modifications can be made for particular disabilities.

Pupils with hearing difficulties benefit enormously from high-quality electronic equipment which picks up sounds, and which can in turn be amplified through the use of appropriate software. The ease of using more visual material further increases the potential for such pupils to gain insights into the ideas being explored and for them to receive feedback of a more detailed nature.

Similarly, pupils with visual impairment are able to benefit through, for example, the use of increased font sizes and variations in the colour balance of texts made available electronically. Such control regarding the presentation of text can also greatly assist students with dyslexia (Becta 2003a). Pupils with very little or no sight can benefit enormously from the use of 'text to voice' software, and programmes which provide commentaries of events.

The range of possibilities for providing access to learning for pupils with physical disabilities is expanding all the time and is probably one of the best documented areas related to the use of ICT. Reports such as *Tools for Inclusion: Science and SEN* (Wall 2001) provide specific advice and further ideas can be obtained from organisations catering for specific disabilities. We should, however, remember the importance of matching the solution to the needs of individual pupils; this may involve trying out several possible devices or software packages. The children concerned should be engaged in this process because not only will it result in a more appropriate solution, but it is also part of the wider learning arena of developing self-worth and key skills such as negotiation, decision making and communication.

Gaining physical access through the use of ICT is, of course, not restricted to students who are in the classroom. Individuals who have a long-term illness, for example, and need to work from home or hospital, are also able to gain much benefit. The use of the Internet and appropriate software packages stimulate interest and spark students' imagination regardless of their schooling environment. Projects such as satellite schools provide education and lessons across most subjects via e-mail and the Internet.

Vignette 1: Making science more physically accessible

In some schools, ICT has become pervasive (but not intrusive) in the classroom. At the Fleming Fulton School in Belfast, for example, the whole science classroom has been redesigned so that ICT is an integral element, providing pupils with full access to the curriculum (Fleming Fulton School 2005). Clearly, this may not be possible in all situations, but there are many resources that can be introduced into virtually every context.

A talking thermometer is one such resource appropriate for visually impaired students, but which can also be useful with other groups of students. The durable probe can be placed in any liquid and, when the button is pushed, an audible spoken temperature reading is given. Other students who are less confident with using thermometers and reading off scales can use the same piece of equipment to occasionally check their readings. The RNIB have developed a wide range of equipment which supports visually impaired students across the curriculum and which are collated in a freely available catalogue (RNIB website: http://www.rnib.org.uk/xpedio/groups/public/documents/code/InternetHome.hcsp).

DiagramMaker (Wilkinson 2003) is another simple to operate resource that allows students (and teachers) to produce accurate, clear diagrams of experimental set ups. This can be particularly motivating for pupils who might not have the patience or motor control to produce accurate freehand drawings of their equipment. The planning stage of an experiment can be frustrating for some students, since they know they are not very good at 'art', and they just want to get on with the practical. Using such a tool to produce diagrams can encourage them to express their own ideas and engage with planning their experiment.

Increasing engagement

In providing an overview of ways in which science can be made more inclusive for children with learning difficulties, Bell (2002) highlights the value of 'hands on' approaches – in other words, of active learning. Children with learning disabilities are more likely to succeed using these approaches because of the reduced emphasis on the use of texts and abstract textual learning in favour of more concrete experiences and physical interaction with the scientific phenomena. Clearly the use of ICT has a role to play in this context. The use of appropriate material provides striking visual and moving images, interactive exercises and games, and authentic sounds and other facilities, all of which can rapidly secure students' attention. Interactive whiteboards (IWBs) and digital projectors, in particular provide, extensive opportunities for individual, group or class involvement. The physical engagement of students using an interactive whiteboard to choose objects or select answers enables them to make non-verbal choices whilst developing physical coordination.

Involving children in quizzes can be easily facilitated through IWBs in particular, making the learning fun and improving the level of engagement. Though not yet extensively available to schools (largely due to the costs involved) interactive voting systems have some potential with pupils being invited to 'press your buttons now'. The immediate feedback opens up a variety of possibilities for a teacher to assess the understanding of a group. Furthermore, the anonymity of submitting opinions in this way encourages the less confident to participate and enables the introduction of a range of controversial questions linked to science which pupils may usually feel inhibited from contributing to openly, for example, 'Should the school canteen sell healthy salads instead of burgers?'.

We cannot stress too strongly the importance of adaptability and flexibility in using such engaging resources, since they must be tailored to the needs of the group. It can be very frustrating to discover an impressive Internet-based animation, only to find that insufficient thought has been given to the accompanying on-screen text, which is hard for the user to access. In this sense, there is much to be said for self-created, adaptable presentations.

Vignette 2: Increasing engagement

The commercial production of robust, easy-to-use digital microscopes has been a valuable addition to primary science resources in recent years. When used to capture close up images of a variety of materials, they can both stimulate and engage students, whilst contributing to valuable pedagogic advancements for the students. Such images can be viewed 'live' as they happen but can also be stored for use on other occasions.

A particularly useful way to do this and produce tailor-made resources for catching pupils' attention is through the development of digital presentations using appropriate software, of which PowerPoint is only one. One teacher, having captured a variety of images of everyday materials, produced a PowerPoint presentation with brief appropriate prompts and questions. The materials and objects featured included sand, a wood knot, a lightbulb filament, ice and a tooth. When using the PowerPoint images the teacher had as many as possible of the objects available, so that having discussed the students' thoughts, their ideas could be related to the real object, making a cognitive link between the image seen and what the object really was (see ASE 2002a for examples).

This is seen as effective inclusive practice since there is limited written language required, it encourages a different approach to the topic of materials and the quiz presentation is engaging for all. Digital microscopes and cameras can be used by students who might like to choose their own objects to be included in the presentation, encouraging a participatory approach and enabling development by individuals who were enthusiastic to experiment further (ASE 2002b).

Although the use of ICT has enormous potential for gaining students' attention so that they engage with the topic being studied, there are limitations. Indeed, it is important to remember the principles of good practice that apply to all teaching but are particularly critical when working with children with learning difficulties. Three issues in particular seem to be relevant here (see Bell 1999 for a more extensive discussion). The first is the attention span of the children involved, who often find it difficult to focus on a task over a sustained period of time. The second is range of problems that children with learning difficulties can have in recognising the key features that are relevant to the task in hand and their tendency to focus on things that attract their attention, but are not directly relevant to the learning objective. The third is the way in which some children with learning difficulties rely to a significant extent on the external cues they pick up from their surroundings in order to respond to questions. This may involve repeating things said or done by other children, mirroring teacher actions and taking information from pictures and other objects in the room, regardless of their relevance. Thus, the use of presentations and other media has many advantages, but there are dangers too. Over-elaboration may become counterproductive and result in students becoming disengaged rather than involved.

Extending and developing the teaching and learning dialogue

At the heart of most, if not all, learning situations is the interaction which takes place between the pupil, the subject matter being studied and the 'teacher'. Science education has been strongly influenced by constructivist approaches to teaching and learning, in which learners are considered to be actively involved in the construction of meaning and understanding of concepts for themselves (see for example Osborne 1996). There has been increased emphasis on the role of the teacher in helping children construct meanings based on their existing ideas and experiences and on the process of scaffolding in creating opportunities for children to engage with new ideas (Morroco and Zorfuss 1996; Bell 1999). We, like others in this volume and elsewhere (Murphy 2003; Harlen 2005), would argue that these principles are central to good teaching in any situation, but that by using ICT we can endeavour to make science accessible to all students in a manner which, at least in part, overcomes the barriers to learning that they experience.

Many of the ideas outlined in the previous section would, if used slightly differently, be effective in extending the dialogue that is such an integral element of teaching and learning. The interaction that can be developed using an interactive whiteboard can involve pupils in, amongst other things, indicating their ideas, showing examples of their work, watching change sequences and predicting what comes next (see Chapter 7). All these and many other ideas also enable formative assessment to take place naturally as part of the learning process.

In describing the development of science materials to support pupils with special educational needs, Bancroft (2002) highlights the importance of developing a multi-sensory approach, using flexible materials which are relevant and age-appropriate to the children involved. While there is much that can be, and should be, done without its use, ICT allows pupils and their teachers to:

- extend the range of their senses so that it is possible to see and hear things that otherwise would be impossible, for example, 'watch' things grow over long time scales, 'slow' things down so they can be recorded, experience things that are very small and very large, and 'visit' places that we cannot otherwise get to;
- capture and monitor changes using sensors, computers and cameras whilst gathering data from experiments;
- access other materials in much the same way that we would with other children.

One of the big differences, however, is the fact that, having captured the information, data and other forms of evidence, it is possible to review them as often as required, enabling students to recall earlier events without having to rely entirely on memory. Effective use of ICT (for example, by rearranging objects on screen, putting symbols in order or ordering pictures to 'tell a story') also helps in the sequencing of events, which many children with learning difficulties find hard to do.

The ability to revisit activities and lesson materials electronically also makes it easier to adapt to meet the needs of a particular group of students by producing differentiated materials. Clarity of written instructions and use of appropriate diagrams can be reconsidered after initially trialling the materials with one group, without having to start all over again. This is a particularly useful facility when working with more able students who require additional stimuli or more challenging questions.

Vignette 3: Extending the teaching and learning dialogue

The use of 'special effects' simulations provides opportunities to help pupils get below the surface, or in this example 'under the skin', of an object. When a class of students were studying bones, muscles and movement, the running person animation was used as part of the starter activity. This allowed students to see the skeleton inside the body moving as the person either runs or walks, visually reinforcing that the skeleton exists to add structure to the body and that specific joints can move in specific ways. The interactive software was used after the student had already been encouraged to feel their own bones and joints. The animation created a focus for the extended discussion, with the group being able to choose which joint or part of the body they wished to explore. It could, of course, also be used when revising or revisiting the topic at a later stage (Evans 2003).

Language in all its forms is often a major barrier to learning in most subjects. As Wellington and Wellington (2002) explain, in science it can create particular difficulties, partly because of the specific vocabulary that is used, but also because of the need to help children develop and describe abstract ideas. Again ICT has a contribution to make in helping children overcome this barrier. *Writing with symbols*[2] is an ICT tool that produces a symbol to go with every word that is typed onto the computer. The symbols are used in different ways by students who find it hard to read. For example, some students might have to rely on a symbol-supported timetable to give meaning and structure to their school day.[2] Other students may use a symbol-supported topic summary word sheet, with the symbols helping them to find the particular word they need to spell. Websites have now been developed incorporating symbols to explain science-related concepts or to provide general information on a topic. One good example is the *Rainforest with Symbols* website.[2] Students can be invited to submit their own pieces of work (or stories) to the website, recognising and sharing their successful work. This is a developing area and there is further scope to be explored in the use of symbol-supported text in science education.

Reinforcement, recording and reporting

As we have already indicated, the potential for ICT to be used as a means by which children can record events and monitor changes during investigations is almost endless. This is a major step forward in helping to overcome some of the barriers to pupils' learning. By building up a bank of information it is possible to help students look for patterns across a range of items in order to, for example, identify similarities and differences between organisms.

With appropriate support and guidance, pupils can build up their own records and reports of their investigations. Given suitable software, they can prepare good quality work for display because the difficulties of writing and drawing can be reduced. For those who find use of the written word difficult, the production of an audio or visual record is now a relatively easy option.

Vignette 4: Reinforcement, recording and reporting

When studying floating and sinking, a group of pupils were given a collection of objects and their task was to predict which would float or sink. The teacher had prepared an on-screen grid in the software with appropriate key words contained in the grid, and students clicked on words from the grid with a mouse to include them in the word processor part of the package. When the group had made a prediction for a particular object, they used Clicker 3 software (see Becta 2005 and Figure 4.2) to record their ideas.

This use of ICT enables students to produce well presented, high-quality outcomes through the use of Clicker. This shows that the students have the ideas but barriers exist relating to them recording or explaining their predictions. The adaptability of the software means that teachers can use it in a variety of teaching topics across the curriculum.

Importantly, the use of ICT also provides increased opportunities for recording pupils' progress, supported with evidence. In the day-to-day bustle of the classroom, it is all too easy to miss the small steps by which children with learning difficulties progress. By integrating the use of ICT, in its range of forms, as part of teaching and learning, evidence of such improvements can be gathered and, when necessary, reflected upon. For example, when exploring bulbs, wires and batteries for the first time, a group of pupils had to try to get the bulb to light by creating a simple complete circuit (ASE and NASEN 2003). As a student successfully completed this task they demonstrated this to the teacher who took a picture of them and their completed task. For students who were not happy to be included in the picture, the teacher took only an image of their hand pushing the switch to complete the circuit. The pictures were saved for assessment purposes and some were used in a classroom display relating to the circuits work. This recognised the students' achievements and provided a visual reminder of the work that had been completed, which could be referred to later as a reminder when revisiting the subject. Approaches such as

Figure 4.2 Using Clicker to support science writing.

this enable the compilation of electronic portfolios for each child, to which they contribute; these can be particularly valuable when developing and reporting on learning plans for individual children. The use of scanners allows children's handwritten work or drawings to be included as well.

Extending the learning community

A feeling of isolation is quite often felt by those teaching science to children with specific special educational needs. It might be the first time that a mainstream teacher has taught a child with autism, or it might be that the science coordinator in the special school has always struggled to teach a specific topic in science. ICT introduces a means for those in geographically diverse locations to share their experiences, ideas and resources in a virtual environment. This connectivity with others can be very reassuring and has been particularly effective for those working with children with special educational needs. For e-mail forums to be successful the numbers registered must reach a 'critical mass', with subtle prompting or leading from the coordinator of the forum, since many of those registered will at first not feel comfortable sharing their views in what is seen as a public domain. This can be illustrated by looking at findings based on the SENCO Forum, which is a well established e-mail forum that has been monitored and researched (Lewis and Ogilvie 2002) during its development. Other successful SEN e-mail forums are operated by Becta (Becta/Ngfl SEN forums) and the ASE also operates the Inclusive Science e-mail group (ISSEN website: http//www.issen:org.uk/).

It can be hard to find specific resources that are identified as really addressing inclusion and special educational needs in science. In the recent past, some manufacturers may have been timid in promoting a resource as applicable 'for SEN' for fear that it might marginalise the appeal of the resource. However, with the inclusion agenda having become a higher priority, this does not seem so much the case today, with manufacturers beginning to refer to accessibility and special educational needs in their promotional materials. However, it is a small start – Becta (2003b) stated that 'only a small percentage of curriculum materials are currently available in alternative formats accessible to those with special needs.' Resources such as the Ngfl/Becta Inclusion website (Ngfl/Becta) have provided a portal for identifying suitable materials and sharing ideas that address these important considerations.

Vignette 5: Extending the learning community

Several groups have been established to provide a means of linking those working with different groups of children. For example, the ISSEN group was set up with an ethos of bringing together expertise in making science more inclusive, and the Becta SEN forums, including the SENCO forum, provide links for ICT and inclusion.

An example of a more local initiative is the *Science To Raise And Track Achievement* (STRATA) project (Oswald *et al.* 2002; STRATA website: http// www.ase.org.uk/sen/sen/strata-schemes.htm) which brought together teachers in Cambridgeshire special schools to develop topic-based schemes of work for science incorporating the p-scales (QCA 2001) and going up to level 4. The process was not only worthwhile for participating teachers, but the resulting schemes have been further disseminated through the Astra Zeneca Science Teaching Trust website. A Continuing Professional Development unit has also been developed to enable other teachers to gain a better understanding of how to make appropriate use of the p-scales with their students. The schemes, having been adopted and adapted by other teachers working in similar environments with ICT, have been the key to disseminating this good practice beyond the original group, saving others from ‘reinventing the wheel’.

Some final thoughts

New forms of technologies are rapidly developing and these will inevitably continue to provide new ways of supporting inclusion in science, particularly regarding accessibility and enabling further independent learning. There has already been increased regulation of website design in the UK (Disability Rights Commission 2004) which will increase the overall accessibility of the Internet. Software tools that automatically convert written electronic text on a website into a symbol-supported text version are already being introduced and recently developed tools to aid those with visual impairment include handheld devices that can scan newspaper text and then be plugged into a television to produce enlarged, legible text.[2]

Recent technology has also supported the development of tactile diagrams that incorporate speech for visually impaired students and others to hear the parts of the diagram named as they touch it. Such tactile diagrams might be a map of the world, part of a car, or the human digestive system, produced in a raised or textured version on a piece of board, so that the diagram can be felt. In the past a support teacher may have explained the diagram as it was being felt, or Braille labels may have been used, but the use of speech synthesis makes them far more engaging and able to be used more independently. The use of electronic notepads that allow students to express their opinions or submit their results to a computer that would collate them centrally would further assist student engagement. Interactive whiteboards have begun to make a large impact in some schools and, as greater numbers are being installed, their use is beginning to be explored by teachers and researchers, reflecting on their potential as a teaching and learning tool, and not only as novel, short-lived practice. This view is further supported by the increasing level of support and guidance that is becoming available through web portals (Becta 2003c; E-learning centre 2005). However, as is concluded by O'Sullivan (2004), who studied the use of interactive whiteboards by students with profound and multiple learning difficulties, being a new, developing technology, there is a need for further detailed research into their impacts and implications for students with special educational needs.

However, as with all areas regarding ICT in science education, there is a need for teachers to receive training relating to its effective use:

> Teachers cite the lack of time, insufficient knowledge of the pedagogical uses of technology, and a lack of information on existing software as three major barriers to integrating technology. Teachers and support staff need ongoing training in order to make informed decisions regarding the technological needs of all students, including those with special needs.
>
> Becta (2003b)

This emphasises that if the use of ICT is to make a real difference for all students then the priority, for the immediate future at least, must be supporting teachers to integrate its use into their everyday practice. Although it is perhaps less exciting than speculating about the potential capability of new ICT hardware and software, it cannot be emphasised too often that the role of the teacher remains key to the effectiveness with which ICT can enhance the learning that takes place. To this end, teachers need to develop confidence in using ICT in combination with subject knowledge and teaching skills. If, by adapting and modifying teaching strategies in small ways, teachers can use ICT to help overcome barriers to learning and make explicit the small incremental steps that are required to help children develop their process skills and understanding of concepts, then we can truly claim we are making science more inclusive.

Notes

1 Further sources of research, policy, pedagogical and curriculum information are available at the following sites:

ACE Centre http://www.ace-north.org.uk/
Astra Zeneca Science Teaching Trust http://www.azteachscience.co.uk/
Dyspraxia Foundation http://www.dyspraxiafoundation.org.uk/
Inclusive Technology http://www.inclusive.co.uk/
Inclusive Science and Special Educational Needs (ISSEN) http://www.issen.org.uk
London Gifted and Talented http://www.londongt.org/homepage/index.php

National Association for Able Children in Education (NACE) http://www.nace.co.uk
National Association for Special Educational Needs (NASEN) http://www.nasen.org.uk
National Grid for Learning/Becta Inclusion website http://inclusion.ngfl.gov.uk/
Royal National Institute for Deaf people (RNID) http://www.rnid.org.uk/
Royal National Institute of the Blind (RNIB) http://www.rnib.org.uk/
The British Dyslexia Association http://www.bda-dyslexia.org.uk
Down's Syndrome Association http://www.downs-syndrome.org.uk/
The National Autistic Society http://www.oneworld.org/autism_uk/
Satellite Schools http://satellitevs.com/ or http://www.satelliteschool.co.uk
STRATA, Astra Zeneca Science Teaching Trust, Cambridgeshire project resources http://www.azteachscience.co.uk/code/development/strata.htm
Symbols World website http://www.symbolworld.org/index.htm
Further contacts relating to special educational needs can be found at http://www.ase.org.uk/sen/

2 Webwide (2005) *Communicate: webwide*, http://www.widgit.com/products/webwide/powerpoint/index.htm (July 2005).
Widget at http://www.widgit.com for *Writing with symbols 2000*, *Rainforest with symbols*, *Class timetable produced using Widgit Rebus symbols* and *Guide to symbol-supported timetable* (July 2005).

References

ASE (2002a) *SY Primary CD-ROM*. Hatfield: ASE, http://www.sycd.co.uk/primary (July 2005).

ASE (2002b) 'Digital microscope PowerPoint presentation', in ASE *SY Primary CD-ROM*. Hatfield: ASE, http://www.sycd.co.uk/primary/ict/cameras-and-microscopes.htm (July 2005).

ASE and NASEN (2002) *Inclusive Science and Special Educational Needs Joint Statement by the Association for Science Education and the National Association for Special Educational Needs*, http://www.ase.org.uk/sen/pdf/sen/docs/docguid_stat.pdf (July 2005).

ASE and NASEN (2003) *Case studies*, http://www.ase.org.uk/sen/further/case-studies.htm (July 2005).

Bancroft, J. (2002) 'Developing science materials for pupils with special educational needs for the Key Stage 3 Strategy', *School Science Review*, 83 (305): 19–27.

Becta (2002) *How to Use ICT to Support Gifted and Talented Children*, http://www.ictadvice.org.uk/index.php?section=tl&rid=631&catcode=as_inc_sup_03&pagenum=5&NextStart=1&print=1 (July 2005).

Becta (2003a) *ICT Advice: Dyslexia and ICT*, http://www.ictadvice.org.uk/downloads/guidance_doc/dyslexia_ict.doc (July 2005).

Becta (2003b) *What the Research Says about Supporting Special Educational Needs (SEN) and Inclusion*, http://www.becta.org.uk/page_documents/research/wtrs_ictsupport.pdf (July 2005)

Becta (2003c) *What the Research Says about Interactive Whiteboards*, http://

www.becta.org.uk/page_documents/research/wtrs_whiteboards.pdf (July 2005).

Becta (2005) *Examples of Practice: The Primary Classroom 2 – Year 4*, http://www.becta.org.uk/teachers/teachers.cfm?section=1_6_1&id=1017 (July 2005).

Becta/Ngfl (2005) *Discussion Forums*, http://www.becta.org.uk/teachers/display.cfm?section=1_1 (July 2005).

Bell, D. (1999) 'Accessing science in the primary school: meeting the challenges of children with learning difficulties'. Paper presented to the Australian Association for Research in Education Conference, Melbourne 1999, http://www.aare.edu.au/99pap/bel99150.htm (July 2005).

Bell, D. (2002) 'Making science inclusive: providing effective learning opportunities for children with learning difficulties', *Support for Learning*, 17 (4): 156–161.

Bell, D. (2003) 'Putting your teaching on the line: making science accessible for all pupils', *Times Educational Supplement Extra Special Education*, December.

Carlisle, J.F. (1996) 'Evaluation of academic capabilities in science by students with and without learning disabilities and their teachers', *The Journal of Special Education*, 30 (1): 18–34.

Davies, P. and Florian, L. (2004) *Teaching Strategies and Approaches for Pupils with Special Educational Needs: A Scoping Study* (Research Report 516). London: HMSO.

Disability Rights Commission (2004) *Formal Investigation Report: Web Accessibility*. http://www.drc-gb.org/publicationsandreports/report.asp (July 2005).

E-learning centre (2005) *Using Interactive Whiteboards*, http://www.e-learning centre.co.uk//eclipse//Resources//whiteboards.htm (July 2005).

Evans, S. (2003) 'Bones, muscles and movement animated resource', in ASE/NASEN *Inclusive Science and Special Educational Needs CD-ROM*. Hatfield: ASE, http://www.ase.org.uk/sen/focus/muscles.htm (July 2005).

Farrell, P. (2001) 'Special education in the last twenty years: have things really got better?' *British Journal of Special Education*, 28(1): 3–9.

Fleming Fulton School (2005) *Recording and Demonstrating Achievement (UK: Northern Ireland)*, http://131.246.30.23/ita/senistnet/cs8.php (July 2005).

Harlen, W. (2005) *Teaching, Learning and Assessing Science 5–12*. London: Sage Publications.

HMSO (2004) *Education (Additional Support for Learning) (Scotland) Act 2004*. London: The Stationery Office, http://www.opsi.gov.uk/legislation/scotland/acts2004/20040004.htm (July 2005).

Lewis, A. and Ogilvie, M. (2002) *The Impact of Users of the National Grid for Learning SENCO Forum Email List*. Birmingham: University of Birmingham, http://www.becta.org.uk/page_documents/teaching/senco-forum1.pdf (July 2005).

Lindsay, G. (2003) 'Inclusive education: a critical perspective', *British Journal of Special Education*, 30 (1): 3–12.

Mittler, P. (1996) 'Preparing for self-advocacy', in Carpenter, B., Ashdown, R. and Bovair, K. (eds) *Enabling Access: Effective Teaching and Learning for Pupils with Learning Difficulties*. London: David Fulton Publishers.

Montgomery, D. (2003) *Gifted and Talented Children with Special Educational Needs – Double Exceptionality*. London: NACE/David Fulton Publishers.

Morroco, C.C. and Zorfass, J.M. (1996) 'Unpacking scaffolding: supporting students with disabilities in literacy development', in Pugach, M.C. and Warger, C.L. (eds) *Curriculum Trends, Special Education and Reform: Refocusing the Conversation*. Williston, VT: Teachers' College Press.

Murphy, C. (2003) *Literature Review in Primary Science and ICT*. Bristol: NESTA Futurelab, http://www.nestafuturelab.org/research/lit_reviews.htm.

NCTE (2005) *Exceptionally Able*, http://www.ncte.ie/SpecialNeedsICT/TechnologyAdvice/AdviceSheets/ExceptionallyAble (July 2005).

Osborne, J. (1996) 'Beyond constructivism', *Science Education*, 80 (1): 53–82.

Osborne, J. and Hennessy, S. (2003) *Literature Review in Science Education and the Role of ICT: Promise, Problems and Future Directions*. Bristol: NESTA Futurelab, http://www.nestafuturelab.org/research/lit_reviews.htm.

O'Sullivan, S. (2004) 'The use of interactive white boards and touch screens by pupils who have profound and multiple learning difficulties'. Unpublished undergraduate dissertation, Anglia Polytechnic University, http://www.parkroadict.co.uk/dissertationtext.html.

Oswald, S., Brewer, P., Cornwell, R. and Grant, J. (2002) 'A scheme of work for special school science: the Cambridgeshire story', *School Science Review*, 83 (305): 29–39.

QCA (2001) *Planning, Teaching and Assessing the Curriculum for Pupils with Learning Difficulties: Science*. London: QCA Publications.

Rose, R. (2002) 'Including pupils with special educational needs: beyond rhetoric and towards an understanding of effective classroom practice', *Westminster Studies in Education*, 25 (1): 67–76.

Solity, J. (1995) 'Assessment through teaching and the Code of Practice', *Educational and Child Psychology,* 12 (3): 29–35.

University of York Science Education Group (2002) *ICT in Support of Science Education, A Practical Users Guide*. York: University of York.

Wall, K. (2001) *Tools for Inclusion: Science and SEN*. London: Institute of Education, University of London, http://www.ioe.ac.uk/nof/tfi/science.pdf.

Wedell, K. (2005) 'Dilemmas in the quest for inclusion', *British Journal of Special Education*, 32 (1): 3–11.

Wellington, W. and Wellington, J. (2002) 'Children with communication difficulties in mainstream science classrooms', *School Science Review*, 83 (305): 81–92.

Wilkinson, S. (2003) DiagramMaker software in ASE and NASEN *Inclusive Science and Special Educational Needs CD-ROM*. Hatfield: ASE, http://www.ase.org.uk/sen/focus/muscles.htm (July 2005).

5

ELEPHANTS CAN'T JUMP: CREATIVITY, NEW TECHNOLOGY AND CONCEPT EXPLORATION IN PRIMARY SCIENCE

Ben Williamson

Introduction

This chapter explores the possible implications for primary science education of children using new technology to create and manipulate visual illustrations and drawings of science concepts. In doing so, it addresses three distinct fields of recent analysis. First, it explores how children's creative activities can be promoted by using ICT to enable science learning to become meaningful to them. Secondly, it identifies how work in children's visual literacy from the field of social semiotics impacts on the ICT-enabled science classroom. Finally, it discusses how previous work on using drawing in the science classroom has allowed children to explore and develop their conceptual understandings of science. This three-pronged approach leads into an analysis of a recent prototype development of a computer-mediated drawing tool, Moovl, which allows children to construct and manipulate dynamic drawings. The chapter then discusses how a greater emphasis on children's creativity and visual literacy in the classroom can impact on their ability to become scientifically inquisitive and exploratory when beginning to investigate science concepts.

Creativity

What does 'being creative' mean? More narrowly, what does 'being creative' mean in the context of science? History has revealed many examples of creative scientists whose discoveries have shocked the world, but often the enduring stereotype of these – as in the cases of Stephen Hawking, Albert Einstein or Isaac Newton – is of the solitary genius scientist surrounded by instruments and chemicals or working on equations at a chalkboard (Driver *et al.* 1996; Osborne *et al.* 2002). Certainly the solitary genius does exist, but this popular view is unhelpful if, as many now believe, we wish to encourage children and young people to be creative while learning science in school. It implies that only the most intellectually able can really 'do science' and that the capacity for 'being creative' is something that these people possess as an innate resource (Robinson 2001). Neither creativity nor science should be seen in such narrow terms. With new technology now becoming more widespread in the classroom it is also necessary to conceptualise the relationship between these tools and the creative learning processes they can promote.

The issue of creativity in science was largely sidelined by the introduction of science as a core subject in the National Curriculum in England and Wales in 1989. For many the National Curriculum for Science reconfirmed the science classroom as a preparatory lab for the minority of students who might go on to study science later at university or beyond (Osborne 2002; Osborne and Hennessy 2003). According to some commentators, the attitudes of many school leavers after 12 years of compulsory National Curriculum science are at best ambivalent and at worst entirely negative (Newton and Newton 1992; Jarvis and Rennie 1998), with many of them lacking familiarity with the core scientific ideas that they will meet outside of school (Millar and Osborne 1998) or holding on to misconceptions that have never been challenged (Vosniadou 1997; Murphy 2003). Studies of children's science education in the primary years suggest that many of their misconceptions and attitudes towards science are formed early on as a consequence of their interactions with particular areas of subject matter (Millar and Driver 1987; Kelly and Waters-Adams 2004).

As a consequence, many have comparatively recently come to recognise that if we wish children to find science exciting and stimulating then we need to make its complexities somehow more accessible. The research literature has increasingly emphasised the importance of children's 'quest for *meaning*' in science (Warwick and Stephenson 2002), the development of children's scientific reasoning skills (McFarlane and Sakellariou 2002) and the promotion of 'scientific literacy' (Osborne 2002; Osborne and Hennessy 2003). These approaches, it is argued, will make science more meaningful for pupils. Broadly concerned with how children construct meanings and understandings through science activities, rather than seeing science as content to be practised and remembered, these are views commensurate with the growing literature in creativity.

Creativity, however, is still not well understood. It remains a well-intentioned, but elusive and ill-defined concept, often used as an umbrella term for disparate activities, skills and processes (Harlen 2004). The case for recognising its value is often made in general terms that simply assert it is a good thing for all individuals, or that define it narrowly in instrumental terms linked to the economy (Prentice 2000). Further, it is important to recognise the distinctions between 'teaching for creativity' and 'creative teaching' (Loveless 2002). In 1999 the publication of the influential *All our Futures* report by the National Advisory Committee on Creative and Cultural Education (NACCCE) characterised creativity as working imaginatively and with a purpose, judging and reflecting on the value of one's contributions to solving problems and fashioning critical responses. The report strongly concluded that creativity should no longer be associated solely with particular 'arts'-based disciplines, but rather as a process that can be mobilised across much wider domains. Others (Overton 2004; Harlen 2004; Howe 2004) have emphasised that creativity is not composed of uniquely creative events but is rather a process for learners of bringing together existing ideas, information and evidence to produce new combinations of ideas. This process, it is argued, is an integral function of learning, and while its activities are slower than more traditional classroom exercises, they facilitate learning that is more meaningful, more likely to 'stick' and more likely to satisfy children and motivate them to continue to learn. In a review of the literature in creativity, Loveless usefully provides a summary:

> Creativity in education can encompass learning to be creative in order to produce work that has originality and value to individuals, peers and society, as well as learning to be creative in order to support 'possibility thinking' in making choices in everyday life.
>
> (Loveless 2002: 3)

A recent special issue of *Primary Science Review* featured a number of practical examples of creative, cross-curricular teaching and learning intended to promote such 'possibility thinking', including field trips to old coal mines and dramatic role-play activities that illustrate such processes of discovery and exploration.

Indicative of the recognition of the importance of creativity to learning across subject domains, the Qualifications and Curriculum Agency (QCA) has established a 'creativity working group' which promotes creativity based on the model of constructivism as extended knowledge building tasks (QCA 2002) and recently launched the 'Creativity: Find It, Promote It' website (http://www.ncaction.org.uk/creativity) to support good practice. The current government's strategy for primary schools (DfES 2003) also underlines the value of creativity as a broad and cross-curricular concern rather than a discrete specialisation. Such work makes it clear that science lessons in primary schools should have a creative, collaborative and cross-curricular emphasis that does not characterise science as an isolated, meaningless discipline, which students find de-motivating.

In science education we might, then, characterise 'being creative' as: working imaginatively with existing ideas, information and evidence; sharpening one's interpretation of them, often by sharing and working on ideas with others; and constructing expressions of the meanings of these ideas, information and evidence that accurately articulate one's personal understanding of what has been achieved.

Creativity and digital technology

As McFarlane (2003) has identified, working with ideas is characteristic not just of creativity but of the ways in which ICT can be used most effectively in schools. Loveless (2002: 12), too, identifies that key features of ICT applications such as interactivity and provisionality 'enable users to make changes, try out alternatives, and keep a "trace" of the development of ideas'. A compelling example of this is provided by McFarlane, who suggests that dynamic simulations offer opportunities for children to interact with and manipulate complex systems:

> The value of dynamic representation is likely to reside in the rendering of the abstract as concrete. For example, it is possible to see, and interact with, a representation of the molecules in a gas [. . .]. By experimenting with the behaviour of these virtual systems it is possible to infer, and understand, the principles underlying often complex and otherwise abstract systems.
>
> (McFarlane 2003: 223).

Such simulations, of course, must be built on adequate models or algorithms of the reality being simulated, which is not always the case: some oversimplify or even misrepresent the phenomena under simulation (McFarlane and Sakellariou 2002). Similarly, caution should be taken with computer simulations since they represent 'cleaned-up' versions of the complex and messy real world (Osborne and Hennessy 2003), and they do need to present viable and convincing alternatives to children's everyday beliefs if their thinking is to develop (Hennessy *et al.* 1995).

One other notable line of enquiry in simulations is recent work in metaphor, particularly visual metaphor. Cameron's (2002) work on metaphors in the learning of science describes a metaphor as bringing together two distinct domains whose juxtaposition activates the possibility of interpretation. These domains, she suggests, are the Topic and the Vehicle, where Topic refers to the actual concept under scrutiny and Vehicle to properties from a related area; operating together, the two domains help to activate the meaning of each distinctly and complement each other. In a development of a science simulation reported by Sweedyk (2005), visual and textual metaphors were recruited to explain the concept of protein synthesis, with the Topic of proteins represented by the Vehicle of elixirs and protein synthesis described in terms of elixir production techniques. The juxtaposition of the Topic with its metaphorical Vehicle, then, may be both visual and verbal, with images and words complementing one another to support the construction of meaning by learners.

However, Osborne and Hennessy (2003) note that the value of interactive computer models such as simulations is not just in representing scientific ideas or phenomena. They can also encourage pupils to pose exploratory 'what-if' questions, to try out and observe what happens when variables are manipulated and to revise both their hypotheses and their investigative practices if they have made mistakes. The capacity to interact with systems that support provisionality, to be iterative in this fashion and to receive immediate feedback can, then, support the development of young people's repertoire of creative and scientific methods. Further, Loveless (2002) suggests that a characteristic of creativity with new technology is the recognition of how the features of particular applications can be manipulated and exploited. The implications for science are that different predictions can be recorded, experiments designed, data and variables can be manipulated, results observed and a range of inferences made. In a classroom equipped with these tools and techniques, then, children can keep a trace of the development of their ideas as they interact with and explore dynamic systems, access information sources, record data, create meaningful representations of their ideas and communicate conclusions or inferences through appropriate media and modes. Loveless (1995) and Claxton (2000) have both suggested that being capable with new technology, however, is more than just competence with a set of skills and techniques; it is subject to an individual's ability to recognise and evaluate the distinctive contributions that new technologies can make to specific tasks and working processes. The use of new technology on its own cannot be described as creativity, then, but the right new technology can certainly be used to support the creative, imaginative and purposeful exploration of science concepts and phenomena.

Three recent examples that use ICT to promote creativity in primary science are the Blaise Castle Project, Savannah and the Bedminster Down Space Centre, all Bristol-based projects. The Blaise Castle Project is an annual fieldwork exercise which saw 700 Year 6 pupils use data-logging equipment, laptops loaded with databases and offline website resources and digital cameras to conduct a thorough survey of insect habitats in a historic park on the edge of Bristol. Pupils took on the tasks of data collection and analysis, documented their activities and discoveries, and afterwards collated their data into multimedia presentations and wall displays. The more experimental Savannah project conducted in March and April 2004 provided children from Year 6 with handheld computers (PDAs) with global positioning system technology to allow them to explore a physical playing field with a virtual map of the African plains superimposed on it. By taking on roles in a pride of lions, the children had to 'scent' their territory, protect their cubs, hunt for food and evade starvation in the dry season. The process of playing the game required them to make predictions about lions' lives on the savannah, to collect data from the field, conduct 'desk research' using websites, books and video and continuously modify their strategies for game-play as the demands of the virtual environment changed. The Bedminster Down Space Centre is a website developed by Bedminster Down Secondary School that hosts local primaries. Children at the primary schools log in to space missions that they are then able to track over a two-week period. The site beams them information about planets and space, and about their chosen space rocket, so that they can then use this information to carry out experiments on electrical circuits, to make presentations about aspects of planetary science and the solar system and to work with others to make sense of complex data sets.

It is not the technical or pedagogical innovativeness of these applications that uniquely positions them as 'creative'. Rather, it is the modes of interaction that they promote which stimulate pupils' creativity. In all three examples, children are encouraged to imagine, suppose and generate ideas; to shape, refine and manage those ideas; to purposely produce tangible outcomes and to act alongside their peers as reflective, critical reviewers. The capacity to manage these disciplines is what makes a learner a creative practitioner and pursuer of meaning.

Many other applications relevant to primary science are discussed elsewhere in this volume. Furthermore, the multimedia capacities of ICT mean that children's exploration and articulation of ideas about science need not be confined to words, but can be expressed in images, sound and action. This chapter will confine itself to examining the role of image-making software and the implications of such applications for strengthening the relationship between creativity and science.

NESTA Futurelab has been working with Soda Creative Ltd to create a tool to support children to work creatively with simple science concepts at Key Stage 1. 'Moovl' is designed as a dynamic doodling environment where it is possible to create interactive drawings that can be animated according to simple rules of physics. Users draw directly on to a tablet

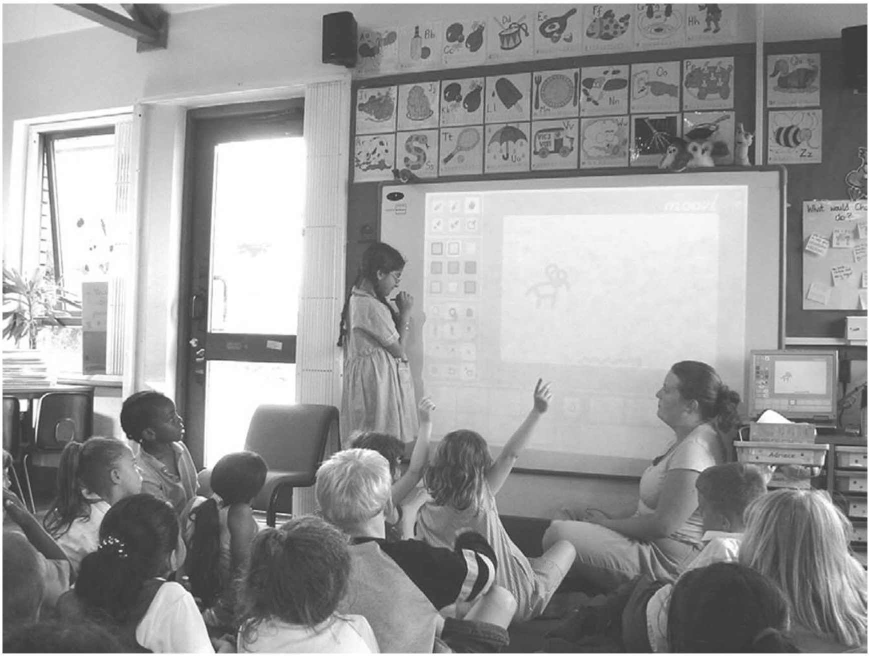
PC using a digital stylus, on to an interactive whiteboard using a stylus or finger (depending on the system) or with a mouse on a PC. Images can be assigned properties which affect how they behave and interact with each other on screen. Each property can be manipulated along a slider scale:

- mass/density – weightless, light, heavy
- elasticity/springiness – very elastic, a little elastic, stiff
- air resistance – no air resistance, some air resistance, fixed
- hardness/collisions – solid, semi-solid, not solid

During trials of the prototype, it was clear that the software could only produce approximations of these physics, not accurate simulations. However, the purpose of the project was principally oriented towards encouraging young children to externalise and manipulate their mental concepts of dynamic phenomena and then to be able to present these to their teachers and to each other. In addition to the doodling functionality, Moovl also utilises the networking capacity of the tablet PCs to allow users to share their simulations through a 'scrapbook' function. The scrapbook allows users to simply 'drag and drop' their images into a series of 'bins' that are then visible to others working on the same local network.

In the study of Moovl being used by children in two classes at a primary school in Bristol (Figures 5.1 and 5.2), we were interested in how children articulate their understandings through their construction of dynamic drawings, how we can interpret their representations and models and, thus, what further work may be required to advance these understandings. In other words, what creative practices were being mobilised by the children in the use of the software? A group of Year 1 children (aged 5–6 years) began to demonstrate how the provisionality of the Moovl program allowed them to take a creative, iterative approach. In one example, pupils Maisie and Connor were illustrating how a group of elephants from *The Jungle Book* (the class reading text for the week) could get across a ravine (Figures 5.3 and 5.4):

Connor: [*quietly to Maisie*] Which one shall we do?
Maisie: Shall we draw a elephant, a aeroplane for the elephant to go in the aeroplane then we need to do a seat on the top
[*Connor drawing*]
Connor: I think they should, I think they should do another bridge
Researcher: Yeah?
Maisie: With lots of wood
[*Connor draws bridge spanning ravine. He tries to move the elephant but finds that it comes apart when moved*]
Connor: Oh. I'll rub him out
[*Maisie takes pen, re-draws elephant*]
Connor: [*takes pen*] Let's see if it works



Figures 5.1 and 5.2 Moovl on whiteboard in Year 1 classroom.

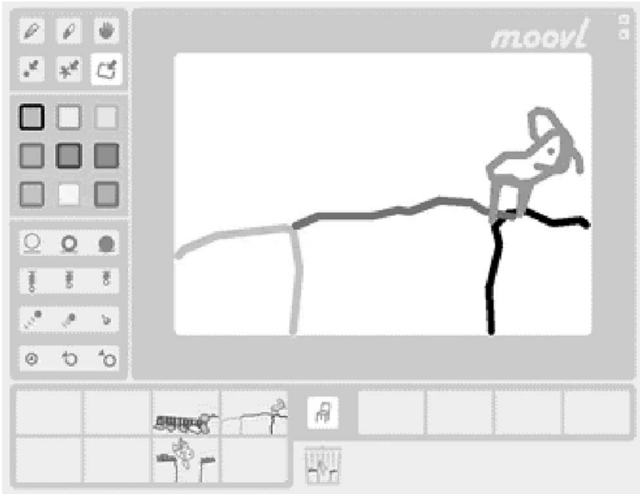


Figure 5.3 Connor's bridge (Year 1).

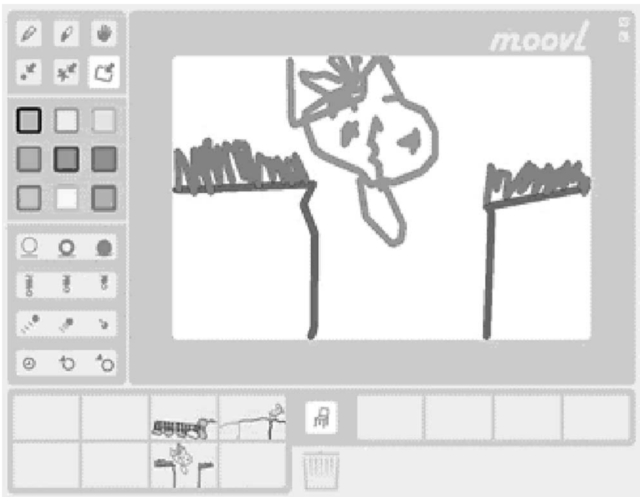


Figure 5.4 Maisie's aeroplane (Year 1).

[*Connor moves elephant across bridge*]
Connor: We did it, we did it already

The process of drawing and trying out shapes with different properties, and then of reviewing the effectiveness of those representations and iteratively redesigning them, is a creative enterprise that could not so easily be accomplished with a pen and paper. This provisionality and the iterative working it promotes is a core creative competence and the software allowed the children to complete the exercise by creating 'workscratchings' and then discarding or elaborating these.

One of the key aspects of creativity in science that has been identified is the ability to be able to ask exploratory 'what-if' questions and then to explore the consequences of taking certain actions or manipulating certain variables in an experiment. The flexibility of Moovl was intended to encourage children to ask such 'what-if' questions, particularly when they are manipulating the properties they have assigned to their images. In the trials of the software a number of the children's questions emerged. These tended to fall into two distinct types of question: those that asked why the software had behaved in certain ways and those that asked whether the software could simulate certain behaviours. The first set included these examples:

'Hey why did it fall down?' (Hanna, Year 1)
'How do you get this to bounce?' (Eloise, Year 3)
'Do you think it's extra springy?' (Marley, Year 3)
'Why's it still bouncing?' (Martha, Year 3)
'How did that happen? What's the mix like?' (Jack, Year 3)
'How come it isn't working?' (Jack, Year 3)
'Why did it go all up there?' (Jacob, Year 3)

The second set of questions included other examples which demonstrate the children beginning to ask more exploratory questions:

'It needs to be thinner, dunnit?' (unknown, Year 3)
'I thought, how do you get the river to move?' (Connor, Year 1)
'How do you make it fly?' (Maisie, Year 1)
'So now you see nothing happens . . . So now what they gonna do? . . . What's this one do I wonder?' (Marley, Year 3)

Another episode from the trial of the software indicated the value of children working together to share ideas, to show each other their drawings and then to make modifications of these based on each others' input. These children were regularly making predictions to one another about the actions the software would simulate if they manipulated their images and the variables in these. In this example, they were illustrating the forces of pushing and pulling and had chosen to picture this as a jumping cat leaping to knock a piece of fruit out of a tree:

Zoe: [*to Sam*] It's going to be a cat, as big as the tree
Kelsey: [*to Sam and Zoe*] We haven't done it yet
Sam: Ah, sucker, you can't do it
Kelsey: We can but we just keep doing it wrong
[. . .]
Sam: [*to Zoe*] Why are you rubbing out the cat?
Zoe: Because it's too big, it's as big as the tree. It may as well not jump if it's going to be as big as it
[. . .]
Sam: [*to Zoe*] Do it, make it bounce more
Kelsey: That was funny
Sam: [*pointing to screen in front of Zoe*] Do it on that one, that one's bigger
Zoe: I don't know what to
[*Sam takes pen*]
Zoe: [*pointing to screen in front of Sam*] I wonder if you make this thing really high up here. Rub that out and draw something really high
[*Zoe tries to take pen*]
Sam: No wait, get off a minute
Zoe: That makes it go really small
Sam: Then . . .
Zoe: Put something really high up there
Sam: You're up in the air . . . Eats something, gets the food [*hands pen back to Zoe*]
Zoe: Can I rub that out?

Sam and Zoe's dialogue accompanies an ongoing process of drawing, erasing and revising as they work out how to get their cat to jump into the treetop where it can push the fruit out of the tree. Throughout their dialogue, the pair conjecture about what features of the program will change the dynamics of the image they have created and they are able to try these ideas out iteratively.

In another example, three pairs of children sitting around the same set of tables launched into a longer dialogue during which a variety of existing understandings were articulated. Again, the children were experimenting with springiness and conjecturing about which sorts of animals they could draw that they could then simulate with the spring functionality:

Marley: What other animals could we possibly do?
Jack: Mmmm, a big blue whale
Marley: No, listen [*inaudible*]
Emily: [*whispers to Marley – inaudible*]

Marley: An elephant? Elephants can't jump
Martha: I might do an otter
Researcher: An otter?
[. . .]
Jacob: The sea doesn't bounce
Martha: It can jump
Jacob: So? The sea doesn't bounce
[. . .]
Martha: Huh a dolphin can jump . . . [*louder*] a dolphin can jump

In this discussion, the children exchanged a variety of understandings. Marley recognises that elephants cannot jump and Martha realises that a dolphin can; Jacob states that the sea cannot bounce. As they discussed these ideas, the children were already in the act of drawing many of these items and manipulating the variables that determined their dynamics. The process of sharing ideas with one another, then, was complemented by the capacity of the software to allow the children to visualise these ideas.

Visual literacy

Osborne (2002: 206) identifies that in the professional domain 'science is a complex interplay of phenomena, data, theories, beliefs, values, motivation and social context both constituted by, and reflected in, its discourse. Science as a professional discipline, in short, is a process that relates the imaginative conjecture of scientists to an evidential base and to the work of others. This, as Osborne points out, is not purely to do with practical activities either. Rather, science is learned and expanded through its discourse – its practices, its representations, and its language, that is, the communicative modes in which ideas are articulated, considered, rejected or received. According to Gee (1996), being knowledgeable and familiar with these discourses leads to the development of 'scientific literacy', where being literate in this sense means developing fluency with the words, actions, values and beliefs of scientists. Even more particularly, it means being critically reflective about the practices of scientists, about the major scientific explanations, the beliefs which underpin them and the ways in which science is used and abused (Osborne and Hennessy 2003). If the emerging emphasis in science education is on how young people make meaning, then scientific literacy is the framework of content understandings and process competencies that will allow them to accomplish this. However, to take the social semiotic view of science literacy, science is bound in discourses and modes of representation which are far from exclusively lexical. Lemke (1998), for example, argues that science sometimes cannot be articulated in the language of words alone; it needs diagrams, pictures, graphs, maps and other visual forms of expression.

Given, then, that science is a multi-modal (Jewitt *et al.* 2001; Kress *et al.* 2001) or multi-semiotic (Lemke 1998) discipline – that is, it involves the negotiation and production of meanings in different modes of representation, from verbal text to image – many have begun to identify the important role that 'visual literacy' can play in science education. For Kress and colleagues, such a view of science education involves the understanding that when a sign-maker creates a representation of scientific phenomena it is to find 'the most plausible form for the meaning that (s)he wishes to express' (Kress *et al.* 2001: 5). In the primary curriculum for Key Stage 1 science there is already a requirement for children to communicate the findings of their scientific investigations in a variety of ways. This includes using ICT and producing drawings, tables, graphs and pictograms. It requires, then, a 'bringing together' of ideas in multiple formats, media and modes, not just for summation but in order to further develop understandings. The science classroom is already multi-modal and multi-semiotic, with emphasis placed on the visual as well as the verbal.

New technology is already beginning to allow children and educators to engage in complex science and dynamic systems (McFarlane and Sakellariou 2002; McFarlane 2003) in ways which are authentic to the actual experience of the observed or perceived world. The multiple modalities of representation that new technology increasingly offers do not just allow children to present creative interpretations of scientific concepts and phenomena; new technology should offer tools which afford children and their teachers the opportunities to think about science and to 'do science' (Osborne 2002) in meaningful ways. In short, it should allow us to be creative, inventive, imaginative and purposeful in science and to perceive science as a process of constantly making meaning.

During the study of Moovl, it was clear that many of the children were able to articulate their ideas in images, but that they were less confident in explaining what images and actions their images represented. Often the children involved in the trial drew images in silence, or spoke very quietly to themselves. What was apparent was that once they had seen others' pictures, many of them would duplicate this and produce very similar images themselves, as in Figures 5.5 and 5.6 which show how two children sitting near to each other had both drawn similar boat designs.

The children, then, appear to have been involved in the wordless exchange of representation, where the actual visual signs represented in their drawings and the dynamic movements afforded by the software allow them to communicate meanings that can then be shared with others. In the above examples, Hamera had been unable to identify how she planned to get her *Jungle Book* elephant across the ravine until she had seen Liam producing his image of the boat. The two pictures indicate

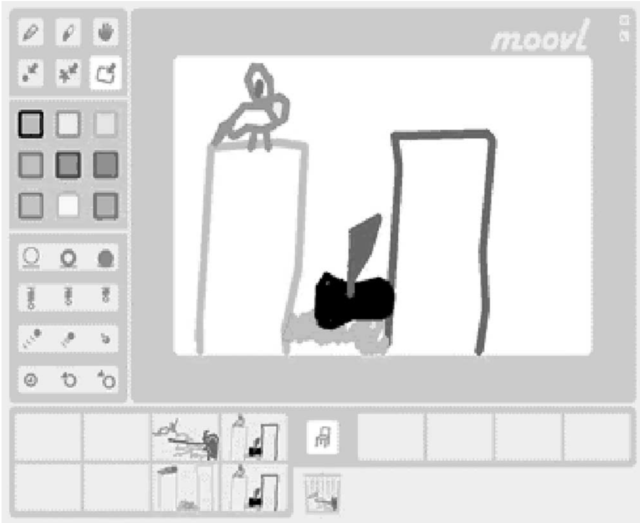


Figure 5.5 Liam's boat (Year 1).

Figure 5.6 Hamera's boat (Year 1).

strongly how her reception of these image-based ideas has influenced her thinking and thus influenced her image.

However, in some cases the children found that communicating in images was more difficult. In this excerpt two Year 3 children, Marley and Amy, had constructed an image of Mr Springylegs, an imaginary crab-like superhero with springs for legs, who they were using to illustrate the behaviours of springy objects:

Marley: Look yeah look I we did it, we did it
Amy: Oh yeah oh yeah
Researcher: Did it work?
Marley: Not exactly how I wanted it
Researcher: Not bad though is it
Everton: [*standing and looking over*] How come it walks?
Marley: It's isn't it's jumping

For Marley, the capacity of the software has limited his ability to represent his idea as well as he hoped. However, being able to illustrate the dynamics of springs seemed to free his imagination so that his representation of this phenomena is framed as an imaginary character who jumps across the screen. Moovl provides the potential for children to create visual, representational models of observable phenomena therefore, to an extent, offering the modalities of animation as a means of describing their perceptions of those phenomena. For this reason the actual images the children create in Moovl can be seen as important visual statements and models of their understandings. These understandings might also be beyond their linguistic grasp to explain, or may provide a better foundation for interpersonal understandings where language alone would be insufficient for articulating their meanings. Clearly, then, the children's representations created in Moovl should be seen as statements of their understanding of phenomena, although we may want to caution against assuming that their production of images accurately depicts their perceptions of the represented objects. As Dove *et al.* (1999) have warned in their study of young children's science drawings, many young children struggle with concepts such as scale, may tend to portray objects such as mountains and rivers according to stereotypical or idealised representations and sometimes their drawings display plain misconceptions. It is likely, then, that science educators in the near future will have to negotiate and interpret the representations created and articulated by children and the meanings articulated in them. These will come in a variety of modes, created in different media, and will be represented through the multi-semiotic discourses that constitute science and through which science constitutes itself. The images that children create in science emerge as purposely motivated signs of what children perceive to be the meanings in the world surrounding them. It is in this fashion that children are able to begin making sense of the science concepts which comprise the science curriculum.

Concept development

Children's conceptual development and their creativity in science are closely aligned. Much of the current emphasis on promoting creativity in primary science stems from two influential projects carried out in the 1990s that emphasised constructivist views of teaching and learning. The STAR (Science Teaching Action Research) project studied classroom practice in relation to process skills (see Russell and Harlen 1990), while the SPACE (Science Processes and Concept Exploration) project investigated children's own ideas about science (for example, Schilling *et al.* 1993). The SPACE project has subsequently informed the foundation for Nuffield's primary science scheme. It approaches the subject through the 'elicitation' of children's ideas about science and then through further activities and 'intervention' helps them towards better understanding of the topics under analysis. In a review of the research literature on children's conceptions in science Wandersee *et al.* (1994) notes that children have a variety of alternative frameworks arising from their personal experiences, observations and social interaction and that these can interact with formal school science learning in unintended ways. Similarly, Duit (1991) has found that children's pre-existing conceptions influence and guide their science learning throughout school. These alternative frameworks, then, need to be elicited by teachers not just so that they can be 'corrected' but so that teachers can design effective curricular and instructional strategies and materials.

The danger that such explicit elicitation of existing ideas – and the subsequent challenging of these ideas – may lead to demoralisation in the classroom (Asoko 2002) needs, however, to be recognised. What is required are classroom strategies which promote surprise and puzzlement and which can then be worked upon by teachers to raise the status of some ideas at the expense of others (Hewson *et al.* 1998). These approaches are broadly constructivist, that is, based on the assumption that children construct or build their own understandings about how the world works and that any misconceptions they have developed are best addressed by engaging them in activities that allow them to re-construct those conceptions. These approaches, then, are equally concerned with children's abilities to communicate to explain science as they are with practical science activities.

It is acknowledged that the creation of graphical images is important in science in allowing children to articulate their understandings of concepts (Cox 1999), as well as for young children's wider development of comprehension about the everyday world that they perceive (Browne 1996;

Kress 1997; Coates 2002). Previous studies of drawing activities in primary science have suggested that it taps children's holistic understanding of phenomena and concepts and that it therefore prevents them from feeling that their understandings are inferior to those of teachers or researchers. Further, many scientific phenomena, such as cloud types or leaf shapes, are better suited to visualisation than verbalisation (White and Gunstone 1992; Dove *et al.* 1999). Research into how children represent scientific concepts through drawing has focused both on specific concepts such as 'insects' (Shepardson 2002), 'the water cycle' (Dove *et al.* 1999), and 'evaporation' (Schilling *et al* 1993), and on abstract concepts such as 'technology' (Rennie and Jarvis 1995) and 'Earth viewed from space' (Arnold *et al.* 1995). Many of these have been intended to probe and detect levels of understanding.

In the Moovl study, the software was being used to elicit from children – through the externalisation of their mental images of phenomena – a range of understandings about dynamics, particularly how the weight and elasticity of objects affects their motion and their behaviour when they collide with or land on top of other objects. In this example, three children from Year 3 were demonstrating one of their images to the researcher:

Jack:	This is a way to cheat – you can't actually go to the bottom, or, a way so that it, you get not that many bounces
Jack:	Oh they're pushing it up
Marley:	Oh cool
Jack:	No they're whacking it and pushing it up
Marley:	Cool
Jack:	And one went through it
Sarah:	There it goes. Make it so it bounces on top of it, like that one does
Jack:	Awesome. Ah it's pushing it down now
Sarah:	Yeah but they will push it up
Researcher:	That's one's bouncing a lot isn't it
Jack:	Ah cool, wicked

During this session, the children were able to articulate their existing understandings about how objects would behave given certain degrees of elasticity and weight and also found that some objects behaved somewhat unpredictably, leading them to manipulate the image further and to conjecture about the likely consequences of doing so. Although a technical problem prevented it from occurring effectively, it was anticipated that the children would also be able to 'upload' their images to their teacher's machine so that they would then be able to present their creations from the whiteboard at the front of the classroom. The availability of such functionality, it is proposed, would have allowed the pupils to present their ideas to their classmates and to their teacher and to stimulate a longer discussion in which the teacher could have guided the development of their understandings by asking them probing questions. However, without this opportunity, the children instead adapted to conjecture and speculation about the affordances of the software and the effects of manipulating it:

Marley: I know what these do. [*points*] That means it's soft
Sarah: What does that do then? [*points to feature on screen*]
Jack: I don't know
Marley: I know
Sarah: What does it do?
Jack: What?
Marley: Squishes the [*inaudible*] underneath [*giggles*] . . . No it means . . .
Jack: That or that's got to be the speed of it
Sarah: What's it really do?

If one problem of using such drawing activities to elicit from children their existing understandings in science is that many of these are based on idealised or stereotypical forms and are hard to displace, or are based on plain misconceptions, then how can a program such as Moovl be used effectively to support the transformation of these understandings? The direct feedback it provides may begin to demonstrate if a particular conception is wrong, but this could just as easily be rejected if children do not understand it or if it is not consonant with their existing frameworks. The mechanism for tackling the issue of alternative conceptions in the Moovl project was to attempt to use the networked, public scrapbook functionality to promote collaboration. By this is meant collaboration between children, but also between the children and their teachers.

Recent work on changing the practices of school science has particularly highlighted the importance of the role of the teacher and the idea of cognition as a product of social interaction (see, for example, Asoko 2002; Watt 2002). Drawing on Ogborn *et al.* (1996), who call for classroom methods that facilitate 'talking ideas into existence', Warwick and Stephenson (2002: 145) state that 'if we are to encourage children to develop an understanding of the meaning of their work in science, there is at least one prerequisite – structured talk that acknowledges that pupils have pre-existing ideas'. In this 'social constructivist' model of learning, in which children and teachers are all collaborators, the curriculum may be subject structured but subject boundaries are often crossed by the teacher's approach as she/he looks at 'ways of making learning meaningful to the pupil by connecting knowledge that is presented in meaningful contexts' (Warwick and Stephenson 2002: 149). This statement, it seems, calls for a modified emphasis in science teaching that treats science as a collaborative subject in which teachers and pupils jointly construct meanings through social interaction, and as a nexus for cross-curricular links with other subjects and, indeed, non-curricular areas.

It was not possible adequately to trial the collaborative functions of Moovl, but the trials did begin to indicate how the software could prompt the kind of surprise and wonder that leads to talk in a creative classroom. The kinds of talk that many of the children were spontaneously engaging in whilst exploring the functionality of Moovl to complete the challenges set by their teachers were often characterised by exploratory questioning, conjecture and speculation. Arguably, the key function of the program is that it allows children to pose such questions and speculations and to simultaneously try out the ideas that emerge. Moovl is not alone, of course, in leading to such inquisitiveness. What we can learn from studying children's use of the program, however, is that multimedia and multi-modal tools provide engagement with ideas at many levels that appeal to many of the senses simultaneously. A box of plastic objects, or a collection of objects that create unique sounds, can have the same effect and be used effectively in the science classroom. The stimulation these tools can encourage in children should be seen as the starting place for the entire creative process of structured exploration and talk.

Conclusions

The research that has been carried out on Moovl and its uses in the primary science classroom is far from conclusive, nor is it intended to be. The purpose of the project was to investigate ways in which more creative and collaborative approaches might be made to scientific investigation to help to promote children's curiosity and enjoyment of science. It is clear that there are problems with Moovl that still need to be properly addressed. Likewise, there is much work still to be done to ensure that schools and the children in their care are using appropriate new technology resources and tools that can expand children's abilities to think and act creatively in science, rather than using resources which simply replicate the textbook question-and-answer standard or which misrepresent science as a field of static knowledge.

As a broad approach, it is critical that science educators understand the value of acknowledging children's pre-existing ideas and of working with children and their multi-modal representations of the world. By working with their existing conceptual frameworks it will be possible to transform these from naïve assumptions to understandings that have meaningful connections with the wider world of experience and of learning.

What the research using Moovl has confirmed is the value of providing young children with tools that can broaden the repertoire of communicational and representational facilities they have available. The process of being able to draw and revise images of dynamic phenomena allowed them to construct simple simulations or representations of real-world behaviours, and to use these illustrations to communicate their understandings. These facilities can act as a prompt to further discussion and have been shown to encourage children to begin asking exploratory questions about dynamics, materials, objects and the relationships between those things. The capacity for children to swap and share images using the scrapbook functionality, too, can promote their ability to review each others' contributions to solving a problem, to assess the suitability of images to fit their purpose and, finally, to collaborate on jointly agreeing on representations that adequately answer the challenges they have been set.

Moovl is fairly unique in allowing children to work with the modalities of the visual in order to begin investigating simple science concepts such as physical properties and dynamics. However, that is not to suggest that it is the only tool capable of being mobilised in the primary science classroom to promote such creative exploration of ideas. Many of the conclusions from the trial study of the software reported here are more widely applicable across the primary science domain. The study has confirmed the value of enabling young children to be creative by becoming actively involved in the construction of meaning. It suggests that children need to be able to articulate their existing understandings of scientific phenomena and then, through multiple modalities including image-making, performing actions in motion, and talking, review those understandings. Children's creativity in science is now recognised as the process of 'bringing together' ideas in multiple modalities, of being exploratory and purposeful while 'playing' with those ideas and of being critical and reflective about the value of those ideas and the ideas of others. In terms related to ICT, creativity can be promoted through tools which allow pupils to manipulate and edit, to juxtapose, to erase and to begin again; in short, actively and critically to construct content rather than passively consume it. Although 'creation' does not necessarily have anything to do with creativity, the ability to make meaning from the world of objects and phenomena from an early age has everything to do with it.

References

Arnold, P., Sarge, A. and Worrall, L. (1995) 'Children's knowledge of the earth's shape and its gravitational field', *International Journal of Science Education*, 17: 635–642.

Asoko, H. (2002) 'Developing conceptual understanding in primary science', *Cambridge Journal of Education*, 32 (2): 153–164.

Ball, S. (2003) 'ICT that works', *Primary Science Review*, 76: 11–13.

Browne, A. (1996) *Developing Language and Literacy 3–8*. London: Paul Chapman.

Cameron, L. (2002) 'Metaphors in the learning of science: a discourse focus', *British Educational Research Journal*, 28 (5): 673–688.

Claxton, G. (1999) *Wise Up: The Challenge of Lifelong Learning*. London: Bloomsbury Publishing Ltd.

Coates, E. (2002) '"I forgot the sky!": children's stories contained in their drawings', *International Journal of Early Years Education*, 10 (1): 21–35.

Cox, R. (1999) 'Representation construction, externalised cognition and individual differences', *Learning and Instruction*, 9: 343–363.

Department for Education and Skills (2003) *Excellence and Enjoyment: Strategy for Primary Schools*. Nottingham: DfES Publications.

Dove, J.E., Everett, L.A. and Preece, P.F.W. (1999) 'Exploring a hydrological concept through children's drawings', *International Journal of Science Education*, 21 (5): 485–497.

Driver, R., Leach, J., Millar, R. and Scott, P. (1996) *Young People's Images of Science*. Buckingham: Open University Press.

Duit, R. (1991) 'Students' conceptual frameworks: consequences for learning science', in Glynn, S.M., Yeany, R.H. and Britton, B.K. (eds) *The Psychology of Learning Science*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Facer, K. and Williamson, B. (2004) *Designing Technologies to Support Creativity and Collaboration*. Bristol: NESTA Futurelab.

Gee, J.P. (1996) *Social Linguistics and Literacies* (2nd edn). London: Taylor and Francis.

Harlen, W. (2004) 'Editorial: creativity and science education', *Primary Science Review*, 81: 2–3.

Harrison, A.G. and Treagust, D.F. (2000) 'A typology of school science models', *International Journal of Science Education*, 22: 1011–1026.

Hennessy, S., Twigger, D., Driver, R., O'Shea, T., O'Malley, C.E., Byard, M., Draper, S., Hartley, R., Mohamed, R. and Scanlon, E. (1995) 'A classroom intervention using a computer-augmented curriculum for mechanics', *International Journal of Science Education*, 17 (2): 189–206.

Hewson, P.W., Beeth, M.E. and Thorley, N.R. (1998) 'Teaching for conceptual change', in Fraser, B.J. and Tobin, K.G. (eds) *International Handbook of Science Education*. London: Kluwer Academic.

Howe, A. (2004) 'Science is creative', *Primary Science Review*, 81: 14–16.

Jarvis, T. and Rennie, L. (1998) 'Factors that influence children's developing perceptions of technology', *International Journal of Technology & Design Education*, 8 (3): 261–279.

Jewitt, C., Kress, G., Ogborn, J. and Tsatsarelis, C. (2001) 'Exploring learning through visual, actional and linguistic communication: the multimodal environment of a science classroom', *Educational Review*, 53 (1): 5–18.

John-Steiner, V. (2000) *Creative Collaboration*. New York: Oxford University Press.

Kelly, P. and Waters-Adams, S. (2004) 'Primary reaction', *TES Teacher*, 20 February: 14–15.

Kress, G. (1997) *Before Writing: Rethinking the Paths to Literacy*. London: Routledge.

Kress, G., Jewitt, C., Ogborn, J. and Tsatsarelis, C. (2001) *Multimodal Teaching and Learning: The Rhetorics of the Science Classroom*. London and New York: Continuum.

Lemke, J. (1998) *Teaching All the Languages of Science: Words, Symbols, Images and Action*, http://academic.brooklyn.cuny.edu/education/jlemke/papers/barcelon.htm.

Loveless, A. (1995) *The Role of IT: Practical Issues for Primary Teachers*. London: Continuum.

Loveless, A. (2002) *Literature Review in Creativity and Learning*. Bristol: NESTA Futurelab Series.

McFarlane, A. (2000) 'The impact of education technology', in Warwick, P. and Sparks Linfield, R. (eds) *Science 3–13: The Past, The Present and Possible Futures*. London: Routledge Falmer.

McFarlane, A. (2003) 'Learners, learning and new technologies', *Educational Media International*, 40 (3/4): 219–227.

McFarlane, A. and Sakellariou, S. (2002) 'The role of ICT in science education', *Cambridge Journal of Education*, 32 (2): 219–232.

Millar, R. and Driver, R. (1987) 'Beyond processes', *Studies in Science Education*, 14: 33–62.

Millar, R. and Osborne, J. (Eds) (1998) *Beyond 2000: Science Education for the Future*. London: King's College.

Murphy, C. (2003) *Literature Review in Primary Science and ICT*. Bristol: NESTA Futurelab Series.

NACCCE (National Advisory Committee on Creative and Cultural Education) (1999) *All our Futures: Creativity, Culture and Education*. Sudbury: DfEE Publications.

Newton, D. and Newton, L. (1992) 'Young children's perceptions of science and the scientist', *International Journal of Science Education*, 14 (3): 331–348.

Ogborn, J., Kress, G., Martins, I. and McGillicuddy, K. (1996) *Explaining Science in the Classroom*. Buckingham: Open University Press.

Osborne, J. (2002) 'Science without literacy: a ship without a sail?', *Cambridge Journal of Education*, 32 (2): 203–218.

Osborne, J. and Hennessy, S. (2003) *Literature Review in Science Education and the Role of ICT: Promise, Problems and Future Directions*. Bristol: NESTA Futurelab Series.

Osborne, J.F., Duschl, R. and Fairbrother, R. (2002) *Breaking the Mould? Teaching Science for Public Understanding*. London: Nuffield Foundation.

Overton, D. (2004) 'A creative science experience', *Primary Science Review*, 81, Jan/Feb: 21–24.

Qualifications and Curriculum Authority (2002) *Designing and Timetabling the Primary Curriculum – a Practical Guide for Key Stages 1 & 2*. London: QCA.

Prentice, R. (2000) 'Creativity: a reaffirmation of its place in early childhood education', *The Curriculum Journal*, 11 (2): 145–156.

Rennie, L.J. and Jarvis, T. (1995) 'Children's choice of drawings to communicate their ideas about technology', *Research in Science Education*, 25: 239–252.

Robinson, K. (2001) *Out of our Minds: Learning to be Creative*. Oxford: Capstone.

Russell, T. and Harlen, W. (1990) *Assessing Science in the Primary Classroom: Practical Tasks*. London: Paul Chapman.

Schilling, M., McGuigan, L. and Qualter, A. (1993) *The Primary Science and Concept Exploration (SPACE) Project: Investigating*, 9: 27–29.

Shepardson, D.P. (2002) 'Bugs, butterflies, and spiders: children's understanding about insects', *International Journal of Science Education*, 24 (6): 627–643.

Sweedyk, E. (2005) 'Games, metaphor and learning'. Paper presented at DIGRA 2005 Conference, Vancouver, Canada, 17–20 June.

Vosniadou, S. (1997) 'On the development of understanding of abstract ideas', in Harrnqvist, K. and Burgen, A. (eds) *Improving Science Education: The Contribution of Research*. Buckingham: Open University Press.

Wandersee, J.H., Mintzes, J.J. and Novak, J.D. (1994) 'Research on alternative conceptions of science', in Gabel, D.L. (ed.) *Handbook of Research of Science Teaching and Learning*. New York: Macmillan Publishing.

Warwick, P. and Stephenson, P. (2002) 'Reconstructing science in education: insights and strategies for making it more meaningful', *Cambridge Journal of Education*, 32 (2): 143–151.

Watt, D. (2002) 'Assisting performance: a case study from a primary science classroom', *Cambridge Journal of Education*, 32 (2): 165–182.

White, R. and Gunstone, R. (1992) *Probing Understanding*. London: Falmer Press.

6

DO COMPUTER CATS EVER REALLY DIE? COMPUTERS, MODELLING AND AUTHENTIC SCIENCE[1]

Patrick Carmichael

Introduction

In this chapter, I will explore how information and communications technology can contribute to the participation of primary age children in 'authentic' learning activities in science and will discuss how in certain circumstances ICT can be a medium with sufficient 'analogical capability' (that is, the ability to express ideas) to allow even young children to engage in tasks in which they 'think like scientists'. In other words, I will discuss whether the integration of ICT into young children's learning environments makes the activities in which they take part resemble more closely the activities of core members of the scientific community. In doing so, I will introduce some of the ideas of Mary Hesse, a philosopher of science whose work on the nature and role of analogical modelling in science may illuminate the thinking and learning of young children.

The chapter draws on the developing field of research into modelling in science and describes some of the features of particular kinds of ICT-based analogical models that might be used to support and stimulate children's learning. The account is illustrated with excerpts from transcripts of interviews and conversations collected in the course of a small-scale research project in which young children (aged 4–10) used a variety of computer programs designed to represent individual animals, communities and whole – albeit simplified – ecosystems. This was initially stimulated by the work of Amy Bruckman, who developed a novel collaborative online environment for children called 'Moose Crossing' (Bruckman and de Bonte 1997; Bruckman 1998), described as a place where children 'can create objects ranging from magic carpets to virtual pets' using a simple programming language. While Bruckman's work was largely concerned with patterns of social interaction, and with knowledge construction and exchange in this online environment, I was more interested in the relationship between children's 'real-world' experience and the representation of objects, particularly living organisms, in what Papert calls 'microworlds', such as Moose Crossing and other virtual environments (Papert 1980: 38).

Science, authenticity and modelling

Following from the radical reassessment of the nature of science by, among others, Hanson (1958), Kuhn (1996) Lakatos (1970, 1974) and Feyerabend (1978, 1987), *authentic science* has been characterised as involving, or at least allowing, the following elements: working and learning in contexts constituted by ill-defined problems; the tolerance of ambiguity and uncertainty; and the expectation that theories may be challenged and ultimately discarded. Individual learning of science is characterised as a 'sense-making' activity predicated on current knowledge, with learners participating in communities of enquiry in which they have opportunities to draw on the expertise of more knowledgeable others (Roth 1999). Roth associates 'authenticity' of learning activities with a view of learning as a 'situated' activity and contrasts this to the artificial nature of most school 'problems'. 'Out of school problems', he argues, 'are not "set" . . . [and] have to be framed as problems before they can be solved. In many cases, there are no prospects to get a "right" solution' (Roth 1999: 14).

For learners' experience of learning and doing science to be authentic, then, they must be involved in the development and application of theory (taken here not necessarily to mean the formalised predictive theories of science, but concepts, models and counterfactuals) and the 'ways of thinking and practising', the 'particular understandings, forms of discourse, values or ways of acting' (Hounsell and McCune 2004) of professional scientists. One of these particular and characteristic forms is modelling. Scientists and science teachers use a range of types of model (verbal, visual, gestural and concrete, amongst others) as they conceptualise, problematise and discuss complex concepts, processes and relationships. In this respect, modelling represents a characteristic 'form of discourse' but they also represent a pattern of engagement with 'real world' domains and problems rather than with a curriculum of predefined problems with 'right answers'. There is no 'right' model for helping to understand a given situation or problem – just a 'currently-best-in-my-opinion' one.

Models have a role to play at every stage in the scientific process from prototyping and 'what-if' statements through to 'textbook' reifications of concepts or processes. Boulter and Gilbert (1998) differentiate between notions of 'mental' and 'expressed' models – for them a model is a representation of an object, event, process or system; mental models are personal, private representations of the target; expressed models are placed in the public domain. Aspects of science, and of the science curriculum, are characterised by different kinds of model and different modes of expression (see Boulter and Buckley 2000 for a useful typology) and any attempt to foster authentic learning in school science needs, therefore, to involve the incorporation of appropriate models. Modelling's claim to a place in the curriculum, however, is not based solely on its being an authentic activity; there is a body of evidence (DiSessa 1986; Mellar 1994; White and Fredricksen 1998) which suggests that a modelling-based curriculum also has the potential to leverage important changes in classroom culture and levels of learner engagement and autonomy. Interestingly, it has been argued that, in most current school contexts at least, Design Technology, with the patterns of modelling it involves and the opportunities for the learner to be designer, maker and evaluator, presents greater opportunities for an authentic role for modelling than does school science (Gilbert *et al.* 2000).

Models also have a role to play in learning beyond merely acting as illustrations or as simplifications of complex situations. Johnson-Laird (1983) describes how inferential reasoning (another key 'way of thinking' for scientists) involves an iterative process in which mental models are progressively elaborated and new ideas generated. This view is advanced by Gentner and Gentner (1983) who, in their work with high school and college students, demonstrated how analogical models are conceptual tools capable of generating new understanding through a process of mapping of features from one domain to another. Nersessian (1992) goes further still by arguing that, in the work of professional scientists, it is analogical reasoning that 'do[es] the work' of problem solving, rather than simply acting as a guide or a heuristic device.

Mary Hesse and analogical modelling

Mary Hesse's view of the role of models in science, advanced in her book *Models and Analogies in Science* (Hesse 1970) is, like that of Nersessian, of models not only as heuristic methods but as a key element of scientific reasoning. She links the process of model building explicitly to the construction of strong but falsifiable scientific theory, a key element of authentic scientific activity according to Popper (1963). Hesse's view of models includes three kinds of analogies – positive, negative and neutral. Positive analogies are aspects of the model in which properties of the model are identical with those of the system it models. So in the context of the kinetic theory of gases, particles may be modelled as being like billiard balls and there is a positive analogy in that both particles and billiard balls obey Newtonian mechanics. There may be, however, some negative analogies as there are some aspects of billiard balls (colour, for example) we do not want to ascribe to particles. There are also neutral analogies – features of the model which cannot yet be reliably classified as positive or negative; these are frequently the basis of fruitful research for scientists, and in the case of the kinetic theory of gases, led scientists to investigate the effects of temperature and pressure on gases. Hesse's model of scientific progress, then, involves identification and subtraction of negative analogies, together with efforts to identify (as positive or negative) any neutral analogies, through a process of systematic enquiry. Neutrality is tolerated – encouraged, in fact – as an aspect of science which may be central to the generation of better understanding and new knowledge, and as such is an 'authentic' concept with which learners of science should be personally and collectively engaged.

What role for ICT?

This discussion of models and modelling raises a number of questions as to the specific role for ICT. Is it, for example, just one of a number of media for the 'expression' of models, or can it act as a bridge between the mental and the expressed models of learners? If we consider the first of these options, it can certainly be argued that ICT has considerable analogical capability by virtue of the range of media it can encompass and the ways in which they can be combined. The fact that learners can interact with highly realistic on-screen environments appears to present opportunities for learning in highly authentic environments – even to the point, as with 'virtual fieldwork', where it is seen as an alternative to working in the 'real world' where distance or danger preclude actual visits. Another argument for the use of ICT in teaching and learning has been put forward by Papert (1980), Resnick (1994) and others; namely, that the availability of 'microworlds' allows a range of patterns of interactions on the part of learners and, critically, the support for learners' risk-taking encourages the authentic behaviour of building and testing hypotheses.

If Papert's 'microworlds' provide a supportive and forgiving context for learners to try things out, then Hesse's view of analogies and models, and of neutral analogies in particular, provides a framework for learning and thinking about the elements of those microworlds. What an appropriate ICT application can provide, then, is a context in which learners are exposed to models in which they are encouraged to identify positive, negative and neutral analogies and provide scaffolding for even young learners in the exploratory, theory-building processes associated with authentic 'thinking like a scientist'.

There are some aspects of computer models that need to be kept in mind, however; they differ from many of the other kinds of models in Boulter and Buckley's typology (2000) in that they are not only the 'expressed models' of individuals other than the learner but also that they may not reflect the consensus views of the scientific community. Many computer models are highly 'edited', but the rationale for, and nature of, this editing may not always be made explicit. There are some notable exceptions, such as simulations written in the Logo programming language, the program code of which may be inspected and adapted (Collela *et al.* 2001), but many more are proprietary products the program codes of which are not exposed to users (see Carmichael 2000 for further discussion of this issue).

What this means is that many computer models have considerable potential to mislead or over-simplify the entities and processes they 'model'. In some cases this is due to decisions being made by designers or programmers as to the content of the program and may be related to perceptions of what is appropriate for the intended audience. In others, the simplification may reflect the difficulty of modelling complex situations and as such a stochastic model may come to be represented in what Boulter and Buckley (2000) call a 'determinative' way. It is difficult to model random motion of particles in a computer model of a gas, for example, and programmers might well use an algorithm to calculate their positions which in fact is deterministic, rendering the model a complex *animation* and, in Hesse's terms, increasing the negative analogy of the model.

Children thinking and practising science with ICT

I interviewed and observed a group of children aged between 4 and 10 (in two groups, 4–5 and 7–10) over a period of about six months, during which time they were able to use a number of software applications in which living things were represented in a number of forms. These applications[2] varied in their scope and complexity, but all involved representations of living things which were to some extent interactive – that is, the children were able to control or influence the behaviours of the simulations of animals within them, so these were more than simply animations over which they had no control. The applications were *Catz* and *Dogz*, 'virtual pet' applications from Mindscape Software (http://www.mindscapeuk.com); *SimAnt*, an interactive simulation in the form of a game from Maxis Software (http://www.maxis.com) and *Vivarium*, an independently produced freeware application developed by Ryan Koopman, which allowed modelling of predator–prey relations in 'microworlds' created and populated with a variety of living things by the children.[3]

The semi-structured interviews that took place involved me sitting alongside the child or children as they used the applications. Initially, the interview structure was limited to the children talking aloud as they 'demonstrated' the applications while I offered some stimulus questions which were, at least initially, based on the expected knowledge about living things from the Foundation Stage and Key Stages 1 and 2 of the Science Curriculum for England and Wales (http://www.qca.org.uk). What I was particularly interested in, following Hesse, was whether (and on what basis) the children identified positive, negative and neutral analogies in the computer applications. However, as we shall see, the interviews, while they remained focused on the applications and the simulated organisms within them, were to range over a rather broader range of issues than curriculum content alone and the 'point-for-point' comparison of simulations with real animals proved to be only one aspect of the children's modelling and learning.

Virtual pets

The youngest children worked primarily with *Catz* and *Dogz* running on Apple Macintosh Powerbooks. They were able to select a cat or dog to be their 'pet' and could choose a template which they could then adapt by adjusting colour and other aspects of its appearance. From the outset, the children referred to 'their' pets and they were regularly 'fed' and 'played with'. The application provides a variety of pet foods, grooming equipment and toys which can be manipulated with the computer mouse, allowing interaction with the virtual pets – the cats, for example, responding to grooming by purring. Even before interviews took place, the children were able to draw parallels between the simulations and real animals of which they had personal experience. They rapidly became familiar with the features of the application and discovered and shared knowledge of undocumented features. In this extract two of the children (A – 4 years old and B – 5 years old)[4] have discovered that it is possible to catch a mouse that periodically runs across the cat's living area and are attempting to feed it to the cat; this involves clicking the computer mouse while the cursor is over the mouse on the screen and holding the 'Shift' key (no easy task and one not documented in the user guide):

A: Got him. Come on mousie, time to die . . . [*drops mouse on to cat's head. Cat ignores it and mouse runs away. B takes control of computer mouse*]
A: Here's the mouse . . . grab him . . . use shift like for the cat
B: Got him . . . wiggle wiggle. Oh . . . he got away again

Those children who had pets of their own, or who had spent time with pet animals of friends or neighbours, were quick to make comparisons between their behaviour and that of the simulations. Here, A describes how Willow (a cat belonging to a neighbour) and the simulation differ in their behaviour – in Hesse's terms, negative analogies – also identifying how the application constrains her behaviour as a user:

A: I wouldn't pick Willow up like that. I'd cuddle him. Not by the leg or tail [*tries to use cursor to pick up simulation by tail*]. Oh . . . oh . . . I can't. You can't pick him up 'cept like this [*uses cursor to pick up simulation by neck*]
R: Maybe you can't pick him up so as you'd hurt him.
A: I can pick Jester [the simulation] up like this [*uses cursor to pick up simulation by neck again. Cat rotates slowly on screen and glares*]
R: Yes, but he doesn't like it, does he?
A: Look . . . look! He's really grumpy!

Other children who had less experience of playing with or caring for real animals were characteristically more cautious in making judgements about the extent to which the simulations were realistic and to identify positive and negative analogies. At the same time, faced with neutral analogies, they were more willing than others to experiment in order to establish the behaviour of the simulations, only stopping to reflect on the realism of the simulations when prompted by an adult. Here, C (5 years old) who has little experience of real dogs, begins by spraying a simulated dog with water – the only sanction, other than denial of food, available:

C: [*Sprays dog nine times. Dog looks depressed, edges away*] He doesn't like that! [*Dog goes to bowl and eats food*] Look at him! He likes that!
R: Is he like a real dog?
C: Mmm . . . yes.
R: If you squirted a real dog, what'd he do?
C: Roar at you . . . Rooaaarrrrr . . . 'cos he's so fierce
R: Do you think this dog ever gets fierce, or cross?
C: No . . .
R: Not ever?
C: [*Sprays dog a further four times. Dog yelps and moves away*] He just gets sad . . .

Even the youngest children were able to identify negative analogies in the simulations, most relating to the lack of realism in potentially dangerous and injurious behaviours. In the *Catz* application, for example, the cats never kill the mouse and they are able to fall from the top of the application window to the bottom without injury. The analogy, initially a neutral one, which most interested the children, however, was the question of whether the simulations could survive without care and food and there were a number of discussions around the issue of whether they would eventually die if left unattended for a long period. A, who had by this time used the application and maintained her simulated cat 'Jester' for several months, describes her experiences and demonstrates an emerging awareness of the analogical limitations of the application.

A: If you don't feed them they d-i-e [emphasis]
R: Have any of your computer cats and dogs ever died?
A: No . . . oh . . . what happens when they die? Do they die like a real cat? Do computer cats ever really die?
R: What happens if you don't use the computer and leave them for a long time? Have you ever done that?
A: I didn't wake Jester [the simulation] up for ages and ages and when I did he was really hungry. His bowl was all empty.
R: Did he look sick, or thin?
A: No . . . no, he was grumpy and meowed a lot like 'feed me, feed me' so I gave him food and biccies and he ate and ate and ate like 'snarf snarf' [*laughs*] . . . like me!

While the animals were perceived as being 'really hungry' (a positive analogy in Hesse's terms) the issue of whether a simulation could 'die' remained unresolved and thus neutral for some time. Despite some of the children leaving their simulations for longer periods (up to six weeks in some cases), no simulations underwent virtual 'death' and the consensus was established among groups of children that while the cats and dogs became hungry, they seemed immortal – a negative analogy recognised by all the children. Only one of the older children (E, 7 years old) recognised the hidden hand of the application designers and developers at work in this, however, and suggested that the negative analogy was imposed to prevent 'upsetting little children if their cat dies', recalling a 'real fuss' a friend had made when another virtual pet had 'died'.

Ecological simulations

Software applications which represented more complex situations (such as Maxis's *SimAnt* which represents an ant colony and Ryan Koopman's *Vivarium* which allows modelling of population growth, competition for resources and predator–prey relationships) were less immediately appealing to the younger children, and even older children had a tendency to misinterpret the purposes of the applications which they regarded as 'games' to be mastered. Lack of familiarity with the subject matter led to children being initially more tentative and subsequently exploring neutral analogies through experimentation, leading to assertions such these:

> 'The mice were better than the bugs because we put more in and they got to the food quicker and had more babies.'
>
> (F, 8 years old)

> 'You got to keep your queen safe 'cos she lays the eggs, and no more eggs, no more ants.'
>
> (E, 7 years old)

> 'The yellow ant (controlled by the computer user) has to get help to carry all that food so she can call up her friends to carry for her.'
>
> (G, 8 years old)

> 'If the slugs' food ran out they eat each other . . . but they never found each other, they just went on and on. The slugs couldn't have babies so they slowly went down and down.'
>
> (H, 7 years old)

As with the virtual pets, the representation of mortality was a point of discussion amongst the children. In *SimAnt*, it was possible for the user's 'representative' (the 'yellow ant') to be trodden on, be eaten by predators or starve to death, but it is 'reincarnated' (the word used by in the application's documentation) back at the nest. Some children chose to interpret this as a negative analogy: 'If you was a real ant, right, and you got squashed, that's it, you've had it. But that wouldn't make much of a game, and you'd get fed up' (E, 7 years old).

Others disagreed and offered the interpretation that the 'reincarnated' ant was in fact a new individual, thus avoiding a negative analogy: 'Ants all live like a family, and the new ant takes over and becomes the boss ant' (F, 8 years old).

Interaction analogies and the 'real world'

The children were able to identify positive analogies (the computer cats were like real cats in terms of appearance, behaviour, appetite) and negative analogies (they were immortal, passive and did not excrete). The children also discussed and explored areas of neutral analogy – a characteristic and authentic activity of science. Hesse, however, identifies 'a further role for analogies' beyond the 'literal, point-by-point comparison of two systems' and the identification of positive and negative analogies – between model and 'target', computer cat and real cat. As we have already mentioned, Johnson-Laird (1983) and Nersessian (1992) argue that analogies can themselves 'do the work' of changing conceptualisations and solving problems.

Hesse, too, developing ideas first advanced by Black (1962), describes (Hesse 1970, 1980) how analogies can be 'interactive'; this involves the transfer of ideas and implications from the secondary system to the primary, involving selection, emphasis, suppression and illumination. As a result of this interaction, 'the two systems are seen as being more like each other, they . . . interact and adapt to each other' (Hesse 1980: 163), even to the point where they may lead to mental models of either system, or both being reassessed. What this means in the context of children's learning is that they have opportunities to 're-experience the world' (DiSessa 1986) and to take part in activities which are authentic science, but which are also personally authentic in that they are relevant to their own development as learners, not just as 'proto-scientists':

E: Look, look, they're making a trail. What have they found?
F: Must be food . . . where's the food?
G: In the hole?
F: Where's the yellow ant?
E: That's in the game. These are all black.
F: Where's the boss ant?
G: In front . . . that must be it . . . no . . . that one.
E: It must have found the food and told the others.

The area in which this kind of thinking and critical reassessment was most evident was in the children's discussions of the relationship between the target domain and the computer application itself, rather than between the target domain and its visual representation on the screen. On the whole, the children found it hard to articulate their understanding of how the simulations worked; only one, E (7 years old) recognised the critical role of the programmer in pre-defining behaviours: 'There's nothing in the computer to say "if you don't eat for ten or twenty or some days then you die", it just says "if your bowl's full then eat some food".'

Lack of technical insight did not prevent children from drawing parallels between the functioning of the computer and living things and, in doing so, going beyond comparative analogies. The question of whether 'computer cats ever really die' is interesting, then, not only as evidence of thinking about the death of a living thing (the *cat* represented by the model), but also because it signals the emergence of thinking about what 'death' might mean in the context of a computer-based model (the *computer cat*), and even of electronic devices more generally (the *computer* through which the model is expressed).

This was also explicitly addressed in discussions of other concepts including intellectual capacity, memory and sleep. In relation to *SimAnt* children started to refer to the computer as 'the yellow ants' brain' and then began to question how the computer could make all of the ants represented onscreen apparently function independently of each other. In the *Vivarium* program, children noticed that smaller 'worlds' appeared to run more quickly: 'The computer's got more work to do and it has to think for all the bugs . . . if you give it too many bugs and things it has to share its brain out and it can't think that much' (D, 7 years old).

In another example, E (7 years old) compared the 'brain power' of different computers and of the cats represented in *Catz*:

R: Do you want to put your cat on a disk and take it home?
E: Mmm . . . yes. Will it work on my computer?
R: Should do.
E: It might be really slow though like [*mimes walking in slow motion*] 'cos it's old [. . .] I don't think it's got enough brain to be a cat. It's not as smart as this one.

Once they had learned to start up and shut down the computers, locate the icons with which programmes were launched and load and save programme files, familiarity with the hardware and software led the children to draw other parallels. The 'sleep' function, which allowed the laptops to conserve battery power, led to comments such as: 'I've put the cats to sleep now. The computer's sleeping so the cats are sleeping too' (F, 7 years old). The question of what became of the cats was discussed by some of the children once they had become familiar with the process of 'minimising' windows. Here, A (4 years old) and C (5 years old) discuss switching between cats:

C: I want to see my cat now. Can I see my cat please?
A: [*speaks into microphone on computer*] You eat your food, and I'll go and talk to the other cats. I'll be back in a moment. [*minimises window on screen, no cats are now visible*]
C: Where's my cat?
R: A, where is your cat now?
A: I don't know, just hanging about. He's OK. He's got food to keep him going.
C: Is he OK? My cat's OK and he was switched off all week.
A: Yes, yes . . . the computer keeps them going. It remembers them.

The interactions illustrated here have the potential to act as starting points in discussions which address questions such as: in what way is a computer's sleep like that of a cat? Or like that of a human? Does thinking of the computer as 'like a human brain' help us understand what it means for the computer to 'sleep'? And conversely, does thinking of the human brain as 'like a computer' help us to understand what it is for *us* to 'sleep'? In the same way, how might thinking of our brains as computers shape our conceptualisation of memory, or our interpretation of the act of forgetting, or of the tendency to be forgetful? As Hesse suggests, a powerful analogy can alter our thinking about both of the concepts or domains that it involves.

Conclusions

The increasing role of ICT in the lives and education of young children makes it necessary for us to develop more sophisticated frameworks for analysing their thinking and learning. Piaget's notion of young children's 'animism' – the attribution of life-like processes such as intention to inanimate objects – remains relevant, up to a point. However, the strategies and complex reasoning demonstrated by the excerpts of children's talk in this chapter suggest that they are able to apply and adapt models as a process of conceptual change (rather than being based on a 'deficit model' in which a crude 'animism' results from incomplete understanding) and that ICT can play a part in enabling this process.

ICT applications can still be seen as addressing curriculum content, but more critical is the potential for learners to identify and explore neutral analogies in specific domains. Ideally, any neutral analogy identified by a learner within a computer application could be suggestive of some kind of virtual experimentation and a review of understanding of the real-world phenomena modelled. Of course, it is when this extends or 'blends' into observation and experimentation of the real-world domain modelled that children's learning becomes more apparent and can be said to have transferred across contexts. In crude terms, it is when knowledge is applied to a real-world phenomenon that the 'learning gains' of the computer application become obvious. But we can take a further step beyond seeing computer-based learning in terms of curriculum content or as a 'microworld'; what the activities reported here promoted through the interaction process described by Hesse was a 'meta-level' of learning about *the value of modelling itself*. What the children were doing was not only comparing a computer model with a real-world situation, but also – when they were talking about the relationship between computers and living things – beginning to address questions about the nature of the medium in which the models were presented.

At the heart of this argument is that view that models, rather than being imperfect mirrors, are opportunities for higher-order thinking and learning even in young children. The challenge for teachers is to stimulate and support this level of discussion; questions of the form 'how is this toy animal similar to and different from a real one?' suggest that, at most, a point-for-point comparison is required. Far more challenging and potentially rewarding are questions which address the iterative processes of model-formation, model-use, model-elaboration and model-abandonment, and which involve 'immersion' not just in an interactive computer environment but in a 'blended' learning experience.[5] Perhaps the greatest contribution that teachers and software designers alike can make is to collaborate in developing a culture of model-building and model-use that supports young learners as they make sense of a world that is, after all, far more immersive and interactive than any 'life on the screen'.

Notes

1 This title was posed as a rhetorical question by one of the children whom I interviewed during my research; the context is explored more fully in the text. It was only after I used it as the title of a conference presentation that people pointed out its resonance with the title (and, for that matter, the content) of Philip K. Dick's novella *Do Androids Dream of Electric Sheep?* Some of the children did indeed have discussions as to the content of the dreams both of real cats and their computer representations, so this chapter could well have been entitled 'Do Computer Cats Dream of Electric Mice?' (I also considered 'The Cats in the Machine'), but I decided to retain the title taken from the 'in vivo' quotation.

2 Throughout the remainder of the chapter the term 'application' will be used to describe the program and the on-screen environment with which the children interacted, whilst the term 'simulation' will be used to refer to specific living things represented within the applications.

3 Despite being listed on a number of web pages devoted to Artificial Life, Koopman's simulation no longer seems to be available online.

4 In the excerpts, A–G are the children; their ages are shown in years and months. R is the researcher – myself.

5 See Collela (2000) and Collela *et al.* (2001) for perhaps the closest approximation to date of this approach to curriculum design.

References

Black, M. (1962) *Models and Metaphors: Studies in Language and Philosophy*. Ithaca NY: Cornell University Press.

Bliss, J. (1994) 'From mental models to modelling', in Mellar, H., Boohan, R., Bliss, Ogborn, J. and Tompsett, C. (eds) *Learning with Artificial Worlds: Computer Based Modelling in the Curriculum*. London: Falmer Press.

Boulter, C. and Gilbert, J. (1998) 'Learning science through models and modelling', in Frazer, B. and Tobin, K. (eds) *The International Handbook of Science Education*. Dordrecht: Kluwer.

Boulter, C. and Buckley, B. (2000) 'Constructing a typology of models for science education', in Gilbert, J. and Boulter, C. (eds) *Developing Models in Science Education*. Dordrecht: Kluwer.

Bruckman, A. (1998) 'Community support for constructionist learning', *Computer Supported Cooperative Work*, 7 (1/2): 47–86.

Bruckman, A. and de Bonte, A. (1997) 'MOOSE goes to school: a comparison of three classrooms using a CSCL environment'. Proceedings of CSCL 97, Toronto, Canada, Dec 1997, http://www.cc.gatech.edu/~asb/papers/cscl97.html

Carmichael, P. (2000) 'Computers and the development of mental models', in Gilbert, J. and Boulter, C. (eds) *Developing Models in Science Education*. Dordrecht: Kluwer.

Carmichael, P. (2003) 'Teachers as researchers and teachers as software developers:

how use-case analysis helps build better educational software', *Curriculum Journal*, 14 (1): 105–122.

Collela, V. (2000) 'Participatory simulations: building collaborative understanding through immersive dynamic modelling', *Journal of the Learning Sciences*, 9 (4): 471–500.

Collela, V., Klopfer, E. and Resnick, M. (2001) *Adventures in Modelling: Exploring Complex, Dynamic Systems with StarLogo*. New York: Teachers' College Press.

DiSessa, A. (1986) Artificial worlds and real experience, *Instructional Science*, 14: 207–227.

Feyerabend, P. (1978) *Against Method*. London: Verso.

Feyerabend, P. (1987) *Farewell to Reason*. London: Verso.

Gentner, D. and Gentner, D.R. (1983) 'Flowing waters or teeming crows: mental models of electricity', in Gentner, D. and Stevens, A.L. (eds) *Mental Models*. Hillsdale, NJ: Lawrence Erlbaum.

Gilbert J. (1998) 'Explaining with models', in Ratcliffe, M. (ed.) *ASE Guide to Secondary Science Education*. Cheltenham: Stanley Thornes.

Gilbert, J., Boulter, C. and Elmer, R. (2000) 'Positioning models in science education and design and technology education', in Gilbert, J. and Boulter, C. (eds) *Developing Models in Science Education*. Dordrecht: Kluwer.

Grosslight, L., Unger, C., Jay, E. and Smith, C. (1991) 'Understanding models and their use in science: conceptions of middle and high school students and experts', *Journal of Research into Science Teaching*, 28: 799–822.

Hanson, N. (1958) *Patterns of Discovery*. Cambridge: Cambridge University Press.

Hesse, M. (1970) *Models and Analogies in Science* (2nd edn) Notre Dame, IN: University of Notre Dame Press.

Hesse, M. (1980) *Revolutions and Reconstructions in the History of Science*. Brighton: Harvester Press.

Hounsell, D. and McCune, V. (2004) 'The development of students' ways of thinking and practising in three final-year biology courses'. Paper presented at EARLI Second Biannual Assessment Conference, Bergen, 23–25 June 2004.

Johnson-Laird, P. (1983) *Mental Models*. Cambridge: Cambridge University Press.

Kuhn, T. (1970) *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.

Kuhn, T.S. (1996) *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.

Lakatos, I. (1970) *Criticism and the Growth of Knowledge* Cambridge: Cambridge University Press.

Lakatos, I. (1974) 'Falsification and the methodology of scientific research programs', in Lakatos, I. and Musgrave, A. (eds) *Criticism and the Growth of Knowledge*. Cambridge: Cambridge University Press.

Mellar, H., (1994) 'Towards a modelling curriculum', in Mellar, H., Boohan, R., Bliss, J., Ogborn, J. and Tompsett, C. (eds) (1994) *Learning with Artificial Worlds: Computer Based Modelling in the Curriculum*. London: Falmer Press.

Nersessian, N. (1992) 'How do scientists think? Capturing the dynamics of conceptual change in science', in Giere, R.N. (ed.) *Cognitive Models in Science*, XVI. Minnesota Studies in Philosophy of Science. Minneapolis: University of Minnesota Press.

Papert, S. (1980) *Mindstorms: Children, Computers and Powerful Ideas*. New York: Basic Books.

Popper, K. (1963) *Conjectures and Refutations: The Growth of Scientific Knowledge*. London: Routledge.

Resnick, M. (1994) *Turtles, Termites, and Traffic Jams: Explorations in Massively Parallel Microworlds*. Cambridge, MA: MIT Press.

Roth, W-M. (1999) 'Authentic school science: intellectual traditions', in McCormick, R. and Paechter, C. (eds) *Learning and Knowledge*. London: Paul Chapman.

White, B.Y. and Fredricksen, J.R. (1998) 'Inquiry, modelling, and metacognition: making science accessible to all students', *Learning and Cognition*, 16 (1): 3–118.

7

'IS THERE A PICTURE OF BEYOND?' MIND MAPPING, ICT AND COLLABORATIVE LEARNING IN PRIMARY SCIENCE

Paul Warwick and Ruth Kershner

> It's quicker with everyone's ideas . . . one person can only think of one thing.
>
> (Helen, Y1/2)
>
> It helps to hear other ideas, even if you don't really understand . . . hearing another idea makes it easy to think of another one.
>
> (Jenny, Y1/2)
>
> With a Starboard everybody can see it, and if you make a mistake with spelling and it's a really easy word you're going to be a bit embarrassed if everybody sees that you've got it wrong.
>
> (Nina, Y5/6)
>
> It's always there on the big thing.
>
> (Ewan, Y5/6)

Introduction

Diverse hardware and software are now employed in primary science classrooms and other chapters in this book reveal the various uses to which they have conventionally, and not so conventionally, been put. In many schools desktop computers can be found in every class in varying numbers, whilst in some they have been replaced by smaller, more versatile laptops. The advent of computer suites and laptop trolleys shared between classes has, some would argue, facilitated a more imaginative use of computer resources. The extensive introduction of interactive whiteboards (IWBs) – literally a 'big thing' in the primary classroom (Ewan, quoted above) – is now making a further contribution to the ways that we think about the impact of such resources on learning.

In this chapter we reflect on work carried out using laptop computers and IWBs in connection with a particular type of software used for 'mind mapping'. We draw upon evidence from our work with UK pupils in Year 2 (6–7 years) and in Year 6 (10–11 years), when we observed science lessons which involved the use of the IWB, laptops and other learning resources. The software used with the IWB was 'Kidspiration' (http://www.inspiration.com/productinfo/kidspiration), a tool designed for use by pupils of primary age. In carrying out our classroom observations and analysis, we were particularly interested in the ways in which the pupils' talk and activity related to their use of the hardware in combination with the mind mapping software and other classroom resources. We videoed teachers working with the whole class in producing mind maps on IWBs, laptop computers and on paper. We also videoed pairs of pupils working on laptops and small groups of pupils working at the IWB, focusing on the ways in which their developing understandings were expressed and negotiated during the activity. After the lessons we interviewed groups of children about their work in these lessons and about their general views on learning with the mind mapping software, the IWB and laptops.

Before going on to discuss the children's responses in these science lessons, we consider some general ideas about children's learning with ICT and the use of mind mapping for representing knowledge and thinking. The value of collaboration between pupils using computers is discussed in the next section, focusing particularly on the implications for learning in the classroom context.

ICT and learning in the primary classroom

As Crook (1994) points out, pupils collaborate and learn in several different ways 'with', 'around', 'through' and 'in relation to' computers. Whilst on some occasions pupils may interact directly with computers in a simulation of dialogue and guided learning, it is more common to see pupils and teachers interacting with each other in the presence of computers and with others beyond the classroom through the Internet. This provides a range of options for pupils' activity, participation and collaboration in the classroom and many teachers will make good use of the different possibilities in each lesson. Yet pupils' learning is not entirely predictable from the provision of certain learning resources and activities because of the individual ways in which each child may respond to the opportunities available in the classroom context. The concept of 'affordance' is useful here, referring back to Gibson's (1979) account of how the physical environment is perceived in terms of what actions it allows. Some objects in the environment are designed to be accessible and efficient to users (Norman 1998) – for example, a doorknob's use is intended to be easily evident to someone who wants to leave the room. The learning environment may seem to a teacher or classroom observer to provide similarly obvious affordances for activity and learning by pupils, but the key point is whether the pupils perceive them as such and respond accordingly.

The assumed connection between pupils' activity and their learning is based in the social constructivist model of learning outlined in Chapter 1. This model explains children's participation in classroom activities as the basis of the creation of knowledge and the development of the higher-level thinking involved in processes like investigation, problem-solving and creativity. The assumption is that learning depends on the collaboration of experienced learners and novices or peers engaged in what is seen to be a purposeful and worthwhile activity. Pupils' direct or peripheral involvement in classroom activities not only contributes to the completion of the task in hand but it also leaves 'residues' in the pupils' thinking which are taken forward to the next activity (Salomon 1996). As Sutherland *et al.* (2004) point out, this process implies three steps in learning where computer hardware and software may have influence:

- the involvement in the immediate learning process;
- the nature of the 'residues' left in children's thinking which affect future learning;
- the decoupling of computer use from a particular lesson so that it can be chosen in the future from the range of teaching and learning tools available in that setting.

These three steps reflect an increasing level of independence and conscious choice for pupils in deciding how best to use the learning resources available to them for different purposes.

The idea of a 'tool' for activity and learning is a central aspect of social constructivism. In the science lessons we observed, both the computer hardware and the mind mapping software can be understood as tools in this sense. A tool may be more than the pencil used for writing or the dictionary used for spelling. It is, broadly, any material or symbolic artefact which people use to carry out both ordinary and specialised activities: cutlery, maps, mathematical formulae, computers and human language are all tools which carry the cultural knowledge and skills of the inventors and previous users. Other people may be perceived as 'tools' when they are involved in assisting or directing activities. In this sense they act to mediate learning and support development by enabling learners to achieve with help what they could not do alone (Vygotsky 1978, 1935). Most tools are so familiar and embedded in daily life that it is hard to imagine what we would do without them. However, certain activities may call for the invention of new tools (ranging from swimming goggles to computer software) without which we could not achieve our goals (to swim in chlorinated water or to simulate the workings of DNA). It is worth noting that tools may both guide and constrain activity, depending in part on the immediate motivation and goals of the people involved in their use (Pea 1993). However, broader educational aims and intentions must also be taken into account. Sutherland *et al.* (2004) remark that ICT tools may facilitate what would otherwise be impossible for pupils, contributing in this way to democratisation, access and inclusion in education. Yet there is a dynamic aspect to the introduction of new educational tools which may lead to unexpected outcomes. One of the general questions that arises in investigating any computer hardware is whether it is just a new form of an old tool (such as IWBs interpreted as replacing blackboards) or whether it is a new tool which may afford fundamental changes in pupils' learning in school. The key question is whether the process is one of replacement or transformation in the classroom? As we see later, this depends at least in part on the teacher's aims and the pupils' responses. A particular issue arising from the research discussed in this chapter is how different tools may be combined in the classroom use and orchestrated by the teacher to best effect in the light of what we know about how children learn and the aims for their learning.

In considering the pupils' learning during this study we focused on both procedural and conceptual understanding in science. The mind mapping software was an important tool which allowed us to highlight both aspects of learning as the teachers attempted to scaffold the pupils' collective construction of knowledge. We were, primarily, interested in how such 'content-free' software might facilitate a genuine exchange of science ideas and how these exchanges and interactions might differ depending upon the hardware used. Before discussing the findings in detail, however, it is worth considering the terms 'mind mapping' and 'concept mapping' as both came up in planning the research and working with the teachers.

Representing knowledge and thinking: concept mapping and mind mapping

The terms 'concept map' and 'mind map' are used interchangeably in much of the literature and in recent years the tendency has been to talk of mind maps rather than concept maps. In trying to understand their nature and purpose, however, we need to consider the literature that refers to concept maps as well as that which relates to mind mapping. Indeed, perhaps the most interesting work exploring the intentions and possibilities of such tools is written referring to concept maps.

In educational settings in particular, 'concept maps' have been used as a strategy for developing metaknowledge and metalearning[1] and there has been much interest over several years in their use in primary science classrooms, both for developing learning and as a technique for formative assessment (Harlen *et al.* 1990; Comber and Johnson 1995; Stow 1997). Whilst the use of such maps always relates to specific content – for example, in connecting ideas in an area of science – an underlying intention in classrooms is usually to enable learners to reflect upon *how* they are coming to develop and understanding concepts and the connections between them.

Concept mapping derives from the early and influential work of Novak and Gowin (1984), who developed the notion of the concept map from Ausubelian learning theory (Ausubel 1968). Novak and Gowin (1984: 4) define a concept as 'a regularity in events or objects designated by some label'. For them, language and other symbol systems are the central tools for such labelling. In essence, a concept map provides a schematic for representing how concepts are perceived to be connected. Whilst there are many ways in which this might be done, the work of Novak and Gowin suggests that it is the ways in which meaningful relationships are drawn between concepts – in the form of propositions – that is the key to their worth in developing not only subject learning but also metaknowledge and metalearning. In Figure 7.1, some exemplars are presented that reflect different levels of propositional thinking.

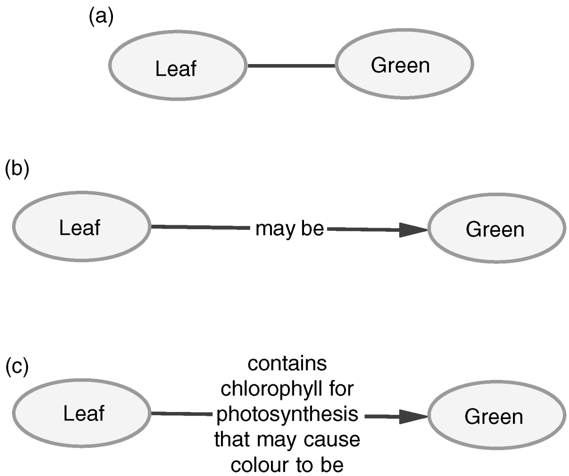


Figure 7.1 Concept maps showing different levels of propositional linking: (a) provides no indication of how the concepts might be connected; (b) suggests a simple propositional link; (c) suggests a more highly developed link in terms of science understanding.

Thus concept mapping 'is a technique for externalising concepts and propositions' (Novak and Gowin 1984: 17) primarily using language. In the simple maps presented in Figure 7.1 (b and c) there is a clear direction in the 'flow' of the map – represented by an arrow – and this is usually a feature of concept maps. As we can see from Figure 7.2, such a directional representation is not always possible to achieve, particularly for younger children. In addition, Novak and Gowin also point to the idea of developing notions of super-ordinate and sub-ordinate concepts within concept maps – this again seems to be only partially realised in the work of primary pupils.

Since the early 1960s 'mind maps' have been used in a variety of educational and business settings to summarise and consolidate information, as an aid to thinking through complex problems and as a means of presenting information (Buzan and Buzan 1993). Mind maps use a combination of different representational tools – pictures, diagrams, words etc. – to show concepts and the links between them. 'Mind mapping' therefore shares both the intention and the structures of concept mapping but there tends to be a greater emphasis on the use of combination of different representational tools to show concepts and the links between them. A further distinction that may be apparent is that concept maps tend to use as their starting point lists of words representing concepts, to be used as and where it seems appropriate to the learner. Though this is perfectly

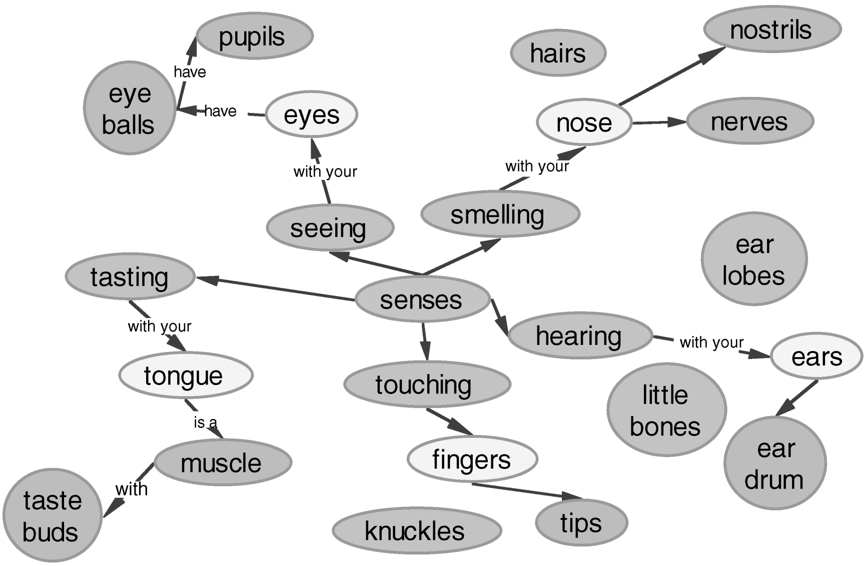


Figure 7.2 A 'typical' concept map produced by younger primary pupils (Year 1/2).

possible with mind maps – and happened on occasions in both our research classrooms – such lists are rarely a *prerequisite* of working with mind maps.

There are now numerous mind mapping software products on the market ('Mindfull', 'Kidspiration' and Logotron's 'Thinking with Pictures' are amongst those appropriate for primary pupils). Most of these include banks of pictures that might represent ideas, the ability to manipulate colour and size, the possibility of creating 'word boxes' of different shapes and the inclusion of 'supergroupers' for clusters of concepts, as well as the organisational possibilities that might be seen in Novak and Gowin's concept maps (i.e. hierarchical structures and directional linkages). Advocates of the use of mind mapping software packages would suggest that because of their flexibility such tools have additional explanatory power beyond that of purely language-based models (Buzan and Buzan 1993).

We will now turn to the science activities that were undertaken in our research classrooms using the mind mapping package Kidspiration with groups working on laptops and at the IWB.

Learning in science: some classroom observations

In the following accounts of science lessons in Year 1/2 and Year 5/6, a number of themes emerge in looking at the pupils' and teachers' uses of the IWB, laptop computers and other tools for learning. One of the main areas of interest is the nature of the collaboration between the children and how they talked to each other during their work. We also became aware of several issues to do with the pupils' conceptual understanding – notably in Year 5/6 the distinction between what might be 'home knowledge' and 'school knowledge'. The representation of existing knowledge (both conceptual and procedural) was particularly highlighted in the use of software imagery and this related to the pupils' perceptions of the software affordances and the associated constraints and opportunities. The public nature of the IWB was important in two ways – not only in influencing the sharing of ideas but also in bringing elements of social evaluation into play (e.g. ensuring correct spellings). There were clearly some key factors relating to technical skill with the unfamiliar software, as well as the level of the pupils' typing and writing skills, which prompted the Y1/2 teacher to mediate and record the group discussion much more extensively than in Y5/6. Observing each whole lesson drew attention to the flow of activity in that time period and the combination of learning tools by the teacher and pupils. The 'orchestration' of learning tools is part of the process of mediation by the teacher and the pupils themselves – a process which not only enables the development of scientific understanding in each lesson, but also serves to connect learning in different lessons and different school and home contexts.

Using IWBs and laptops in Y5/6 and Y1/2

In the Year 5/6 classroom (with children aged 10–11 years) the first activity using Kidspiration was the creation of a mind map of concepts related to 'Planet Earth and Beyond'. The second was an attempt to create a mind map for a fair test of a balloon-powered 'jet'. One group – of between four and six children – worked on the IWB in each lesson. Groups of between two and three children worked on the same tasks at laptop computers.

In the work on 'Planet Earth and Beyond', collaboration between all the pupil groups was apparent during most of the lesson. With the laptop groups the influence of pre-mapping teacher-guided discussion was very clear in the initial stages of the work. Pupils took it in turns to input data, with initial discussions being focused on who should write what and whether terms were spelt correctly, rather than on what should be included. They placed a great deal of information on their maps very quickly, using 'school knowledge' to define the direction of some of their work – 'we need to write about the moon and the Earth and the sun'. As the lesson continued the nature of the activity changed. There was clearly a selection being made from group knowledge for inclusion on each map and sharing of information across groups occurred, with evidence of a subsequent 'filtering' process that determined what each group would adopt as part of their map (Figure 7.3). The pupils, who at this stage were quite unfamiliar with the software, were very concerned about the representation of ideas and the connections between them. Pictures were mainly used to illustrate text boxes, but we noticed discussions reflecting a concern that picture sizes should suggest, as far as possible, relative planet proportions. (As an aside, there was a charming moment when one child who had just found a picture of the Earth asked her partner 'is there a picture of Beyond?')

For the group working on the IWB, the most striking outcome was that the map created included a fraction of the information in those from the laptop groups (Figure 7.4). Why was this? Class procedures – such as checking spelling – were particularly important to the children on the 'public space' of the IWB. Group size and role decisions all used time and some technical issues with the wireless keyboard were apparent. However, it was noticeable that the discussions about what could and should be included on the map, and how the information should be represented and orientated, were at times extensive. For example, strong consideration was given to which type of concept 'holder' should be used to represent the importance of an idea. The group was focused on the board at all times, often gesturing to indicate approval, disagreement or a need to alter the ideas being expressed. Arriving at a consensus seemed very important to these pupils, with ideas often only used if 're-voiced' by more than one group member. Rules for map construction similarly had to be agreed – for example, it was decided that most links should be arrows, with a

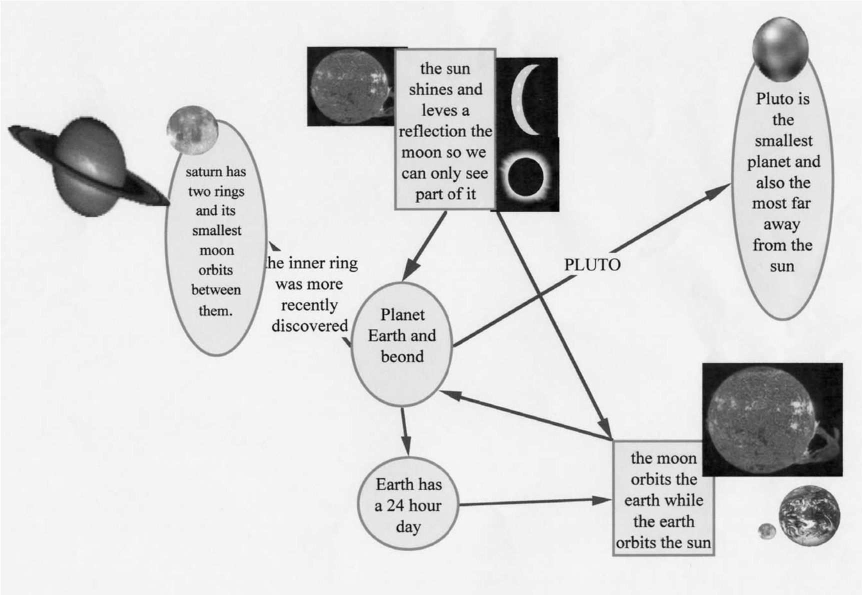


Figure 7.3 A 'Planet Earth and Beyond' mind map produced by a pair of pupils working at a laptop computer.

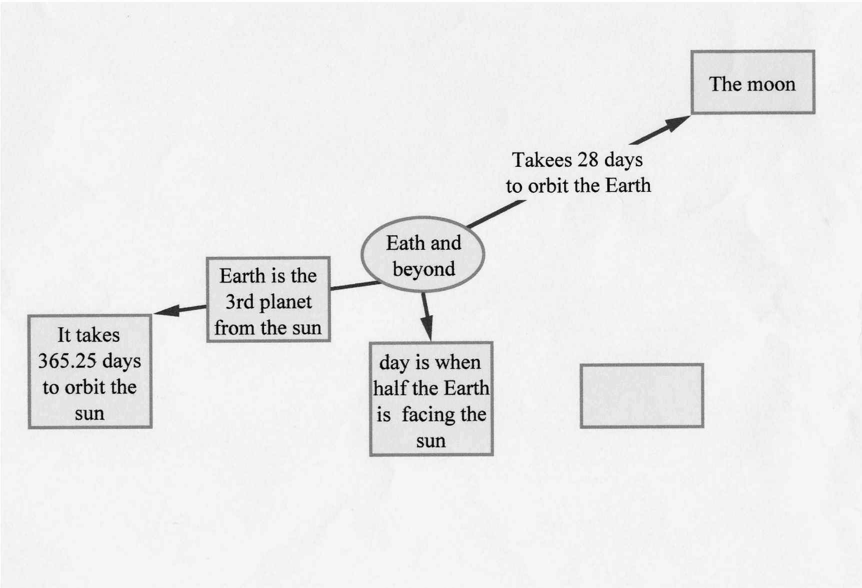


Figure 7.4 A 'Planet Earth and Beyond' mind map produced by a group of pupils working at an IWB.

directional meaning in linking concepts. Struggling with this construction seemed to help the process of deciding how best to show what was understood.

Many of the features noted above reappeared when the pupils were working on their design of a fair test investigation. Now more experienced in the use of the mind mapping software, the focus on procedural rather than conceptual categories led in some cases to a quite different approach by the children. All groups found the idea of a 'main idea' (which is part of the software presentation) impossible to interpret for this activity. The tendency was to group ideas connected to parts of the investigation, either through incorporating them within a 'super-grouper' or through the use of linking arrows (Figure 7.5). Here the affordances of the software were clearly being used by the pupils, yet it is noticeable that at least one of the groups working on the laptops used a simple list to define the experimental method, reverting to a familiar form of representation that might more easily have been achieved by other means. Here, one girl seemed to

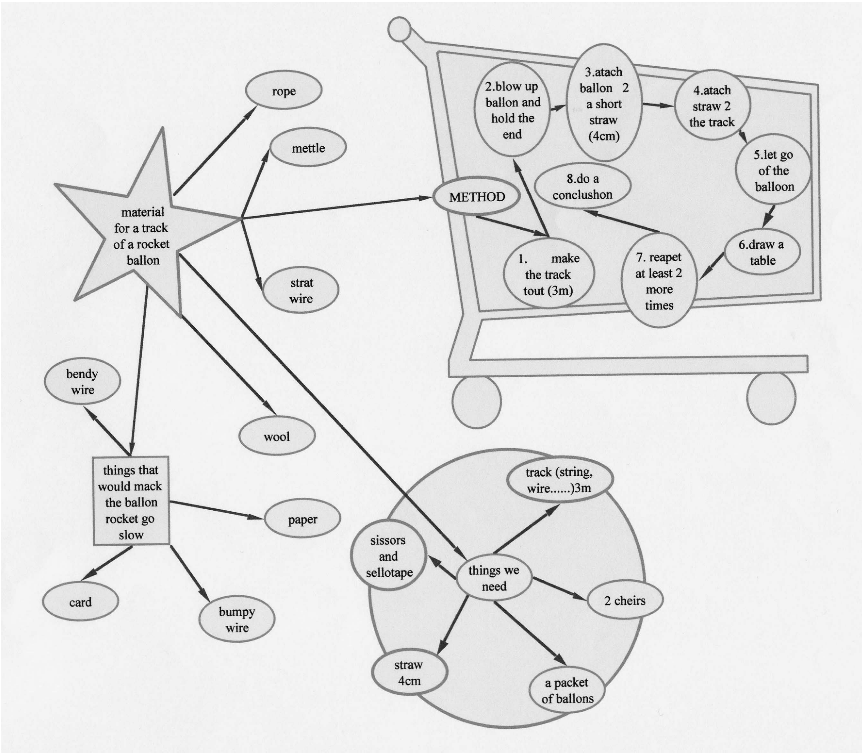


Figure 7.5 A concept map reflecting procedural understandings related to an activity with a balloon jet – laptop group.

be looking for ways to present her work as she would on paper – 'where's the bullet points?' (Figure 7.6)

Other affordances were, however, seized upon – modification of the content of concept boxes, or moving them to other parts of the map, happened regularly. Talk about *how* ideas might be represented was even more prevalent than in previous work – the idea that these representations had to mean something *to others* seemed to be at the centre of struggling to present the ideas clearly. For example, in re-organising and re-sizing concept boxes a child explained to her partner that it was 'so that everyone understands it'. In collaborating across groups, the pupils developed their own thinking – in one case a member of a group used another's map to pose serious questions about methodology, with the questioned pupil sufficiently convinced to say 'that's what I think' at the end of the exchange. For one group, teacher input using the flipchart was highly significant, providing a modelling of content that stimulated a complete re-working of the mind map. It could certainly be argued that the pupils would have been less willing to engage in this re-modelling if they had been working on pencil and paper.

For the IWB group, the negotiation of ideas again generally took longer

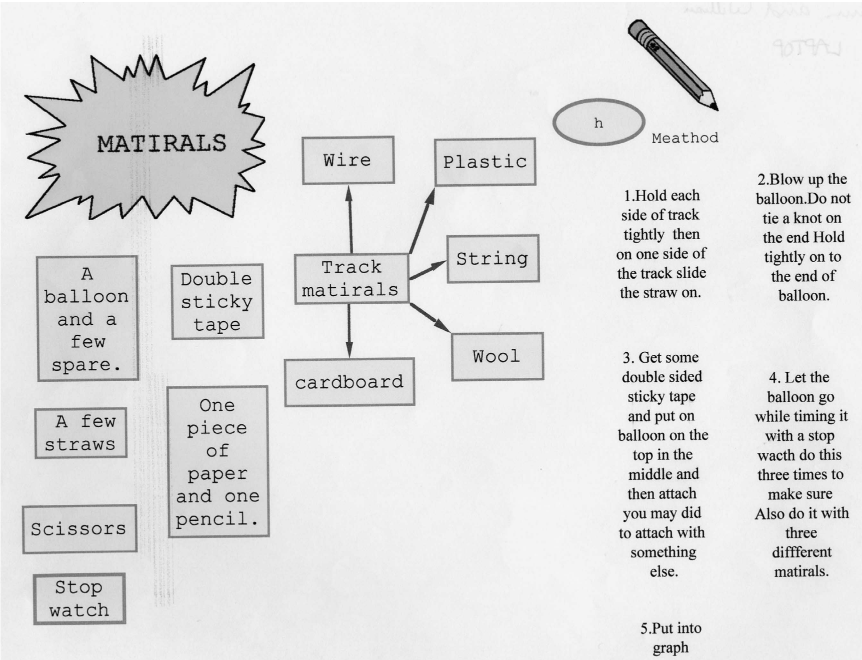


Figure 7.6 Using the software to produce a 'conventional' planning structure for the balloon jet activity – laptop group.

than with the laptop groups and consensus was usually, though not always, seen to be important. In many ways they were using the IWB to create a block of ideas and not in any substantive way using the affordances of the software. Overall, however, use of the software certainly led to a greater consideration of the relationship between representation and the meanings others may take from the completed group maps, hence the prevalence of discussions about the relationship of different forms of representation on the screen – pictures, words, symbols – and the links that should be made between them if an effective presentation of group thinking was to be created for others.

In the year 1/2 class (with children aged 5–7 years) the mind mapping software was used for three distinct purposes:

- to create a map of connected concepts about the human body, reviewed later from the perspective of work carried out in class;
- to allow the children to speculate about the concept of biological variation;
- as a basis for the construction and exploration of ideas related to a 'cars down ramps' friction investigation.

All of these activities were conducted with the whole class, with the teacher acting as an expert mediator of the pupils' ideas.

For the human body mind map, the teacher had pre-prepared the IWB screen to include key pictures and words to stimulate the children's thinking. This allowed the teacher to control the broad areas of discussion that might take place and so to focus the work on her curriculum objectives. She was able to mediate pupil responses, direct children to look at connections and probe their understanding where she felt they had more to offer. In reviewing this human body map, she focused the children's attention

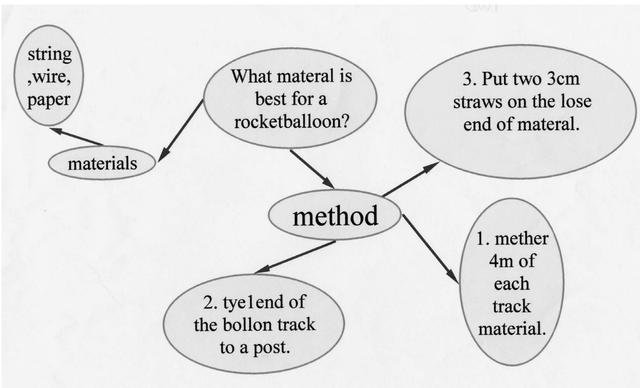


Figure 7.7 A mind map reflecting procedural understandings related to an activity with a balloon jet – IWB group.

on specific areas – such as healthy living – which had been the focus of classroom work. Here the children were concerned to introduce ideas and about exercise and about the kinds of drinks that might be considered to be healthy. Figure 7.8 presents the completed mind map.[2]

With such young children this guided, whole-class approach seemed highly effective in encouraging the children to think about school learning and to compare their thoughts with those of others. This recursive process of visiting and re-visiting information on the IWB is something that can be seen with other IWB software formats, for example notebooks. In this development work, the mind map allowed the children to revisit their initial thinking, to elaborate on their understanding of parts of the map and to draw connections between the major ideas presented.

In an ambitious later use of the software the teacher attempted to use the children's knowledge from their work on the human body to develop a wider conceptual framework related to the idea of biological variation. The teacher had placed words that she wanted the children to try to use – variation, same, different, humans and animals – in concept bubbles along the top of screen, together with pictures (in this case of people and

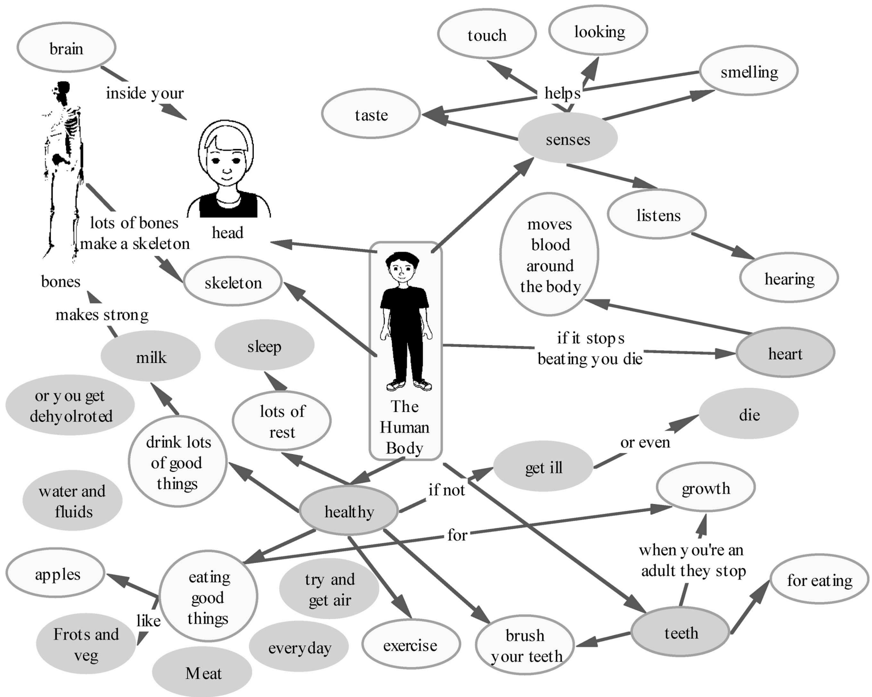


Figure 7.8 A completed human body mind map – Years 1/2 using the IWB with the teacher as mediator.

animals) that she felt the children might find helpful. Numerous ideas were elicited, from the simple – 'you could link animal with the cat' – to those that expressed more complex understandings – 'humans and animals are both living things . . . they eat food' (Figure 7.9). This public process of eliciting ideas (Howe *et al.* 2005) allowed the pupils to comment on the ideas of others and to develop what they knew. Using the software helped the teacher to physically point to the ideas noted on the screen whilst encouraging the children to express existing ideas and develop novel connections between them.

In the final lesson observed, this Year 1/2 class was engaged in developing a plan for a fair test investigation. Again, the teacher had pre-prepared a screen on which she had placed several areas of the consideration in devising a fair test investigation (Figure 7.10). During the lesson, she used the IWB to collect and orientate information from the children about how the investigation should be conducted. She used a range of additional tools to support the children's developing ideas, most notably a 'chest' containing all of the possible equipment the children might later use in their own investigations. By inviting the children to select objects from the chest and asking them how these might be used within the context of the proposed investigation the teacher was able to stimulate discussion, elicit ideas and build a framework of understanding on the mind map that could be used when the children engaged in their own investigation.

Physically, the teacher was in complete control of the IWB – she used

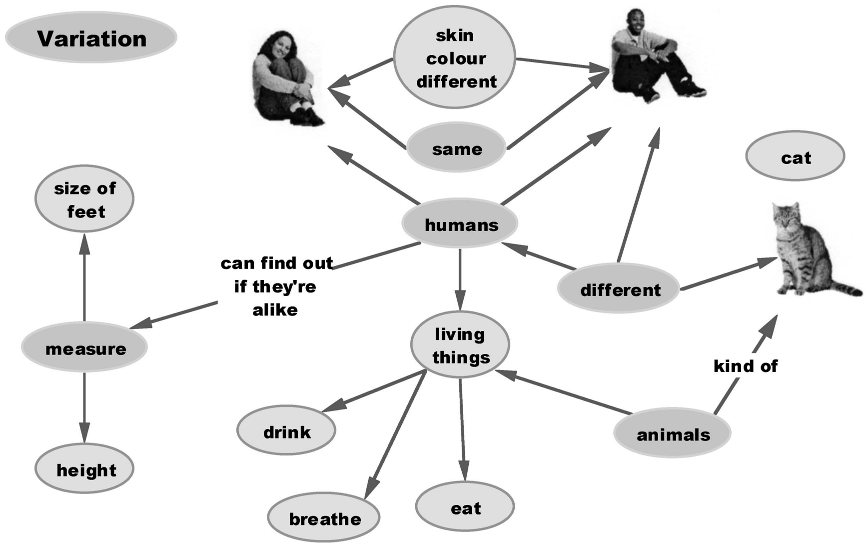


Figure 7.9 An ambitious attempt to map ideas related to biological variation with Year 1/2.

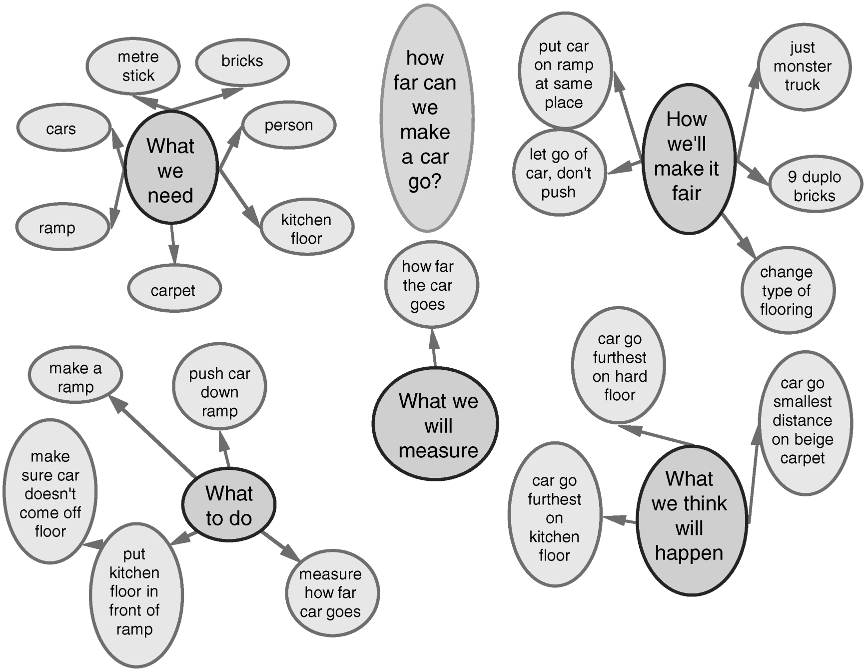


Figure 7.10 A teacher-created, pupil-adapted screen used on the IWB to stimulate discussion about a fair test activity with Year1/2.

the keyboard to write the content of the concept boxes, controlled the orientation of the concept boxes to one another and produced the links between the concept boxes. But in doing this, she was merely the physical operator of the technology – the ideas came from the children, as did the reasons for making the links that were eventually made on the map. She guided, questioned and challenged the pupils throughout the lesson, skilfully mediating their ideas and creating the conditions by which the children could see how they interrelated.

In orientating the children to the task, ideas from a previous lesson were discussed. The teacher used familiar tools – just as the Year 5/6 teacher used her flipchart – to focus initial interest and discussion. Each time a child retrieved an item from the chest the children were asked about the characteristics and possible uses of the objects: 'it's smooth'; 'we could use it as a ramp'; 'to make the car stop'. As a result, they were asked to express their thinking in relation to concrete objects and during the rest of the lesson they were encouraged to try things out using the equipment that they had retrieved from the chest. In discussing what would be the best way to proceed they were encouraged to challenge one another's ideas and to justify themselves, with the map being used as a public tool for orientating ideas that might work.

For teachers attempting to develop procedural understanding – the 'thinking behind the doing' of science (Gott and Duggan 1995: 26) – rather than to simply teach the skills associated with science investigations, this lesson illustrated how the visual presentation of ideas and the ways in which they are orientated to one another can help achieve this aim. In the following task, the children were led to a shared orientation. This seems fundamental to all that we have said so far and provides a clear example of how teachers might be involved in 'the creation of activities which necessitate learning dialogues' (Wegerif and Dawes 2004: 2).

In interview, these young children were clear that this was a very different exercise to the process of creating a map in which all of the boxes might in some way be seen as being conceptually related. At a simple level the concept groups created on the investigation map were understood as discrete elements – different parts of the process – that could be considered separately despite being part of the 'big picture' of the overall investigation. With respect to technical issues, there were obvious problems associated with the speed with which these young children could type on the computer keyboards, despite having received keyboard training. When the teacher herself used the keyboard the 'flow' of the lesson was much improved.

Some conclusions

The emerging findings from this research draw attention to certain key themes and issues relating to the pupils' classroom collaboration, their developing knowledge and understanding, their involvement in multiple aspects of learning in the primary classroom environment and the significance of the teacher's aims and strategies for learning and assessment. These are briefly discussed in the next sections.

Collaboration and talk, and learning to collaborate

One of the main principles informing the work discussed in this chapter is expressed well by Wegerif and Dawes (2004: 1), who argue that '. . . (l)earning with computers in school is a social activity in which the teacher plays a crucial role'. Yet we cannot assume that all primary pupils have the motivation and skills to collaborate in ways that promote their learning, even when provided with opportunities to be involved in tasks such as the ones that we have described. Perhaps to be truly effective, children need to experience something akin to the Nuffield Thinking Together project, which focuses on how children might be taught to interact and talk productively in the context of science. Dawes (2004: 685) remarks that the

Thinking Together project 'provided a core of talk skills lessons that enabled classes of children to generate and agree to use "ground rules" for exploratory talk'. We should note that, as in the case of our research, groups of pupils may be extremely adept at collaborating and respecting one another's views because of the ethos already established in the classroom and the whole school. However, this cannot be taken for granted and, as discussed by Kutnick and Manson (2000), certain pupils may need additional support to develop the social competence in relationships with others that allows them to take full advantage of the social interaction needed for collaborative learning.

Knowledge and understanding in science learning – making connections

The lessons discussed in this chapter draw attention to the importance of understanding how children develop and represent their knowledge in different contexts. In the Year 5/6 class the teacher explicitly told the pupils that for the purposes of that lesson she wanted to know what they had learned in school that term, not just the factual knowledge about the planets which they had gained largely through their homework. She used another classroom tool, the flipchart, to list some key concepts such as 'day and night' and this provided a visible representation of pupils' school learning to prompt them as they worked on their own maps. This tactic helped to mediate the pupils' 'home' and 'school' knowledge effectively and many were then able to begin to combine the two areas of their thinking. As Hart (2000) points out, the principle of making connections between the pupils' classroom responses and their wider learning experiences out of school is central to the thinking required of teachers and pupils and it is one of the fundamental ways to enhance learning and inclusion. The idea that teachers and pupils will combine the use of different classroom tools to make connections in learning draws attention to the need to place the use of any one resource, such as the interactive whiteboard, in the context of activity in the whole classroom environment. As we have already seen in Chapter 5, the work of Kress *et al.* (2001) extends this point in examining how pupils construct their understanding using a 'multi-modal' interplay of resources in speech, writing, gesture, action and visual images. Kress *et al.* (2001: 13) ask 'what constraints and possibilities for making meaning are offered by each mode present for representation in the science classroom, and what use is made of them?' The use of these different ways of representing knowledge is at the heart of the learning process, especially in attending to the connections that are made between them in science learning. Our lesson observations notably drew attention to the relevance of examining gesture, movement and other physical activity by teacher and pupils, in connection with the more familiar uses of speech, writing and visual images.

Multiple aspects of learning in the whole classroom environment – a question of control?

Individual tools such as the IWB do not stand alone in the classroom, but we do need to acknowledge that a particular resource may have specific and distinctive characteristics which can support, or hinder, different aspects of learning. For example, it was very clear from our study that the public nature of the IWB could have advantages and disadvantages. It could clearly help groups of pupils to share ideas with an easily visible point of reference. However, pupils were also aware of the possibilities for social evaluation as their work went up on the large screen and several were concerned about publicly demonstrating their technical skills including accurate typing and spelling. In discussing their review of research literature on ICT and pedagogy, Cox *et al.* (2003) identify one of the emerging themes as the control of learning. They note that work such as that by Hennessey *et al.* (2005) with teachers in secondary schools suggests that the use of ICT can be associated with a decrease of direction from the teacher and an increase in pupil self-regulation and collaboration. In our case both class teachers were concerned with involving the pupils in the learning, handing over as much as possible to them without withdrawing support all together. The idea that responsibility for learning can comfortably be shared by the pupils in the whole classroom environment, with all the prioritising, risk-taking and public errors implied, may be a goal to work towards as ICT tools become embedded in each primary classroom.

Teachers' aims and strategies for learning and assessment

This last point leads us to reflect on the centrality of the teacher's aims for pupils' learning in each lesson. The science lessons described in this chapter highlighted different views about whether the main focus would be on pupils' inclusion in the processes learning or on the assessment of what they had learned. This reflected alternative perceptions of what the mind mapping software could and should do in the given lessons. Yet these apparently alternative aims need not be contradictory. The classroom learning environment is a complex system which supports different aims and objectives for any one lesson. For example, Collins *et al.* (1996) propose the following framework of elements in the learning environment, expressed in terms of what teachers may want pupils to do:

- participating in discourse, for the purposes of active communication, knowledge-building and shared decision-making, as well as receiving information;
- participating in activities, in the form of purposeful projects and problem-solving, as well as practising exercises to improve specific skills and knowledge;

- presenting examples of work to be evaluated, which may involve both performing for an audience and demonstrating the ability to work out problems or answer questions.

These types of activity represent a mix of expectations and views about how children learn, including what may seem to be contradictory aspects of direct instruction and collaborative learning. However, Collins *et al.* (1996: 688) remark that most teaching and learning environments contain all these elements and that 'the most effective combine the advantages of each type'. Social constructivist models of learning emphasise the fundamental importance of the *processes* of participation, communication and active learning, but pupils are also asked to demonstrate their knowledge and achievements in relation to the science curriculum and more widely. Clarity about the priorities and multiple aims for pupils' learning is essential for developing the combined use of ICT tools in productive ways. Detailed classroom observations and further discussion with teachers and pupils can provide evidence of what they see as the opportunities for learning afforded by the computer software, hardware and other classroom tools in combination. However, there is more work to be done on what it really means for pupils to 'interact' with tools such as the interactive whiteboard and useful evidence may emerge as pupils continue to take on more responsibility and control in their use. This type of growth in pupils' involvement in learning is likely to be one of the main indicators of a fundamental transformation in teaching and learning as a result of new interactive technologies.

Notes

1 For the purposes of the discussion in this chapter, metaknowledge might be defined as knowledge about the nature of knowledge and knowing, whilst metalearning refers, essentially, to learning about learning.

2 It's worth noting that, whilst the arrows on this map denote connections between ideas, they do not necessarily always represent the directional proposition or links proposed by Novak and Gowin (1984) for concept maps. This feature of the maps is much more prevalent in the work of the Year 5/6 class, where the teacher placed much greater emphasis on the *nature* of the links between concepts.

References

Ausubel, D.P. (1968) *Educational Psychology: A Cognitive View*. San Francisco: Holt, Rinehart and Winston.

Buzan, T. and Buzan, B. (1993) *The Mind Map Book: How to Use Radiant Thinking to Maximize your Brain's Untapped Potential*. New York: Penguin.

Collins, A., Greeno, J.G. and Resnick, L.B. (1996) 'Environments for learning', in De Corte, E. and Weinert, F.E. (eds) *International Encyclopedia of Developmental and Instructional Psychology*. Oxford: Pergamon/Elsevier Science.

Comber, M. and Johnson, P. (1995) 'Pushes and pulls: the potential of concept mapping for assessment', *Primary Science Review*, 36: 10–12.

Cox, M., Webb, M., Abbott, C., Blakely, B., Beauchamp, T. and Rhodes, V. (2003) *A Report to the DfES – ICT and Pedagogy: A Review of the Research Literature*. Norwich: HMSO.

Crook, C. (1994) *Computers and the Collaborative Experience of Learning*. London: Routledge.

Dawes, L. (2004) 'Talk and learning in classroom science', *International Journal of Science Education*, 26 (6): 677–695.

Gibson, J.J. (1979) *The Ecological Approach to Visual Perception*. Boston: Houghton-Mifflin.

Gott, R. and Duggan, S. (1995) *Investigative Work in the Science Curriculum*. Buckingham: Open University Press.

Harlen, W., Macro, C., Schilling, M., Malvern, D. and Reed, K. (1990) *Progress in primary science*. London: Taylor and Francis.

Hart, S. (2000) *Thinking through Teaching: A Framework for Enhancing Participation and Learning*. London: Fulton.

Hennessey, S., Deaney, R. and Ruthven, K. (2005) 'Emerging teacher strategies for mediating "technology-integrated instructional conversations": a socio-cultural perspective', *Curriculum Journal*, 16 (3).

Howe, A., Davies, D., McMahon, K., Towler, L. and Scott, T. (2005) *Science 5–11: A Guide for Teachers*. London: Fulton.

Kress, G., Jewitt, C., Ogborn, J. and Tsatsarelis, C. (2001) *Multimodal Teaching and Learning: The Rhetorics of the Science Classroom*. London: Continuum.

Kutnick, P. and Manson, I. (2000) 'Enabling children to learn in groups', in D. Whitebread (ed). *The Psychology of Learning and Teaching in the Primary School*. London: Routledge Falmer.

Norman, D.A. (1998) *The Design of Everyday Things*. London: MIT Press.

Novak, J.D. and Gowin, D.R. (1984) *Learning How to Learn*. Cambridge: Cambridge University Press.

Pea, R.D. (1993) 'Practices of distributed intelligence and designs for education', in Salomon, G. (ed.) *Distributed Cognitions: Psychological and Educational Considerations*. Cambridge: Cambridge University Press.

Salomon, G. (1993) 'No distribution without individuals' cognition: a dynamic interactional view', in Salomon, G. (ed.) (1996) *Distributed Cognitions: Psychological and Educational Considerations*. Cambridge: Cambridge University Press.

Salomon, G. (1996) *Distributed Cognitions: Psychological and Educational Considerations*. Cambridge: Cambridge University Press.

Stow, W. (1997) 'Concept mapping: a tool for self-assessment?', *Primary Science Review*, 49: 12–15.

Sutherland, R. with the InterActive Project Team (2004) 'Designs for learning: ICT and knowledge in the classroom', *Computers and Education*, 43: 5–16.

Vygotsky, L.S. (1978/1935) *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

Wegerif, R. and Dawes, L. (2004) *Thinking and Learning with ICT*. London: Routledge Falmer.

8

EMERGENT SCIENCE AND ICT IN THE EARLY YEARS

John Siraj-Blatchford

As the Curriculum Guidance for the Foundation Stage (CGFS) makes clear, in the early years 'Children do not make a distinction between "play" and "work" and neither should practitioners' (QCA 2000: 11).

Within the CGFS the provisions for Knowledge and Understanding of the World provide the foundations for science education and the Early Learning Goals also suggest that, before children complete their reception year they should find out about and identify the uses of technology in their everyday lives and use computers and programmed toys to support their learning (QCA 2000).

The CGFS provides a series of 'Stepping Stone' statements that identify progression in science in terms of children's critical attitudes, their observation, recording and classification skills. My *Chambers Concise Dictionary* defines a stepping stone as 'a stone rising above water or mud to afford passage' and this seems highly appropriate in this case. The general principles or philosophy to be applied in providing an appropriate early education in science are not at all clear. The 'waters' are indeed murky. At Key Stage 2 the National Curriculum increasingly specifies the knowledge and understandings that are to be taught quite explicitly. As you move down through Key Stage 1 the orders tend to be less specific and refer to more general notions, like developing a respect for evidence and exploring similarities and differences. But there is no clear theorisation of the learning transition from early exploration to science education 'proper' (de Boo 2000).

Unfortunately, as we know, when educators are unsure of what they are doing they tend to keep very close to the script, or in this case to the stepping stones (so that they don't fall in!). In the circumstances the last thing we want is an early science education that is restricted to 'delivering' the stepping stones.

So what does it mean to support children's early learning in science? First, in understanding the nature of science education in the early years crucial distinctions have to be made between:

- natural phenomenon and behaviour;
- established scientific theories and explanations;
- children's individual scientific theories and explanations.

Learning science is not simply 'knowing about natural phenomena'; it provides a set of socio-historically established and agreed logico-mathematical constructions that explain these phenomena. But in the early years we cannot expect children to have experienced, or even to be aware of, all of the natural phenomena that they will later learn to explain in science lessons. A fundamental aspect of early science education is, therefore, to provide these awarenesses and experiences, to set the foundations for future science education. It is for this reason that provisions for sand and water play are very popular in the UK. However, the evidence suggests that without some form of scaffolding or instruction (e.g. demonstration, modelling etc.) the play involved may be repetitive, irrelevant and unproductive (Hutt *et al.* 1989, Siraj-Blatchford 2002a). Certainly, for this sort of play to be educational in terms of science, clear objectives need to be defined. Efforts should be made to draw children's attention to the workings of their own body and of the world around them. Imagine how difficult it would have been to understand atmospheric pressure if you had never gained confidence in conceiving of air as a substance beforehand! We can encourage 'air play' in the nursery, pouring it upside down in water, playing with bubbles and balloons, pumps and inner tubes, watching the effects of the wind and catching it in kites and sails.

To understand the problem of teaching 'established science' in the early years we need only consider the case of floatation. It is clear that any adequate understanding of the science of floatation must involve the concept of density and this will only be understood when children are able to consider the effects of proportional (and inverse proportional) changes in volume and mass – the intellectual equivalent of rubbing your stomach and tapping your head at the same time. At the Foundation Stage few (if any) children will be ready for this. Yet practical explorations of floating and sinking may be very valuable in the early years. Children can compare the buoyancy of small and large, heavy and light objects and we can encourage them to begin to develop hypotheses about floatation. But as Edwards and Knight (1994) have argued, in doing so we should only ever be trying to move children from their initial limited conceptions to 'less misconceived' ideas. The development of a practical recognition of the phenomenon of 'upthrust' might also provide a valuable support, if not a necessary prerequisite, for later understanding the scientific explanation.

A 'fact' is, as Margaret Donaldson (1992) has argued, something perceived and consciously noted. For scientific purposes it is also something described and recorded. But the business of perceiving and describing are quite different. For example, we don't consciously perceive everything that is available to our senses and there are many (perhaps an infinite number of) ways of describing what we perceive. Take the example of heat flow: science tells us that when we leave the warmth of our beds to stand bare-footed on a tiled floor, the excellent thermal conductivity of the tiles causes us to loose heat. But what we 'feel' is the sensation of the tiles being cold! A child may perceive and consciously note the fact that she feels warmer when she puts a coat on. But she will not have consciously perceived that heat was leaving her body before she did so and she therefore won't consciously perceive that the coat is providing an insulating layer that traps the heat around her. To the child the coat is simply warm. As Donaldson (1992: 161) says, 'theoretical preconceptions and reported observations are by no means independent of one another. Theories – or, indeed, beliefs not conscious enough to be called theories – guide the nature of the observations; and the guiding assumptions are often not recognized as being open to doubt.'

In the past many writers have referred to the child as a 'natural scientist' (Bentley and Watts 1994) because of their natural inclination to 'spontaneously wonder' (Donaldson 1992) about things. Driver addressed this directly in her book *The Pupil as Scientist*:

> The baby lets go of the rattle and it falls to the ground; it does it again and the pattern repeats itself . . . By the time the child receives formal teaching in science it has already constructed a set of beliefs about a wide range of natural phenomenon.
>
> (Driver 1985: 2)

As Driver (1985) went on to suggest, we now know that some of these beliefs differ markedly from accepted scientific knowledge and that they may be difficult to change. These are the 'misconceptions' that science educators in schools must later engage with. But the major difference between the scientific knowledge that every individual child builds up as an infant and the science constructed by professional scientists is not that one is 'right' and the other 'wrong'. It is related to the rigour with which every new 'scientific' idea is tested and to the benefits of professional collaboration and communication. 'Established' scientific knowledge is the product of a collective historical enterprise. When we refer to science as a 'discipline' we also draw attention to the fact that it constitutes an intellectual enterprise that has a distinct set of rules and that these rules are normally (or properly) adhered to by that particular academic community we know as 'scientists'. For a child (or for anyone else) to think 'scientifically' means to obey these rules and to keep an open mind, to respect yet always to critically evaluate evidence and to participate in a community that encourages the free exchange of information, critical peer review and testing. This latter point is crucial because, as Driver *et al.* (1996: 44) again put it, 'Scientific knowledge is the product of a community, not of an individual. Findings reported by an individual must survive an institutional checking and testing mechanism, before being accepted as knowledge.'

For all of these reasons it is important that we remain vigilant in our use of the term 'science' and discriminate clearly between 'scientific development' as itself a cultural phenomenon (and a knowledge base that children will be introduced to later in school), and cognitive development which, however analogous it may be to science, remains essentially an individual affair.

As Hodson (1998) has suggested, the contradiction that is often assumed to exist between the need to provide an enculturation into established science and the development of personal frameworks of understanding is in any event a false one. Even professional scientists who are working with the same theory while pursuing different purposes tend to apply different 'levels' of understanding. As Hodson (1998) goes on to argue, at whatever stage of education is being considered, the 'personalisation of learning' should involve the teacher in identifying and constructively engaging with the prior 'knowledge, experience, needs, interests and aspirations' of every learner.

Young children are naturally curious and we can encourage their explorations. We can also encourage an early interest in science, and the development of a respect for its achievements. As I have argued elsewhere (Siraj-Blatchford and McLeod-Brudenell 1999; Siraj-Blatchford 2002b), for all of these reasons it is important that we differentiate between a 'science education' that focuses on established conceptual knowledge (in the UK National Curriculum this currently starts in Key Stage 1) and an 'emergent science education' that focuses on hands-on experience, the development of emergent conceptions of the 'nature of science' and the development of positive dispositions to the subject.

In terms of learning theory and child development such 'emergent' approaches move us away from the simplistic notions of individual cognitive elaboration through 'discovery' to see effective practice in sociocultural terms involving the educator and the child engaged together in a 'construction zone' (Siraj-Blatchford and MacLeod-Brudenell 1999).

The large-scale and highly influential Effective Provision of Preschool Education (EPPE) project (Sylva *et al.* 2004) and the Researching Effective Pedagogy in Early Childhood (REPEY) project (Siraj-Blatchford *et al.* 2002) research suggests that adult–child interactions that involve some element of 'sustained shared thinking' are especially valuable in terms of children's early learning. These were identified as sustained verbal interactions that moved forward in keeping with the child's interest and attention. When children share 'joint attention' or 'engage jointly' in activities we know that this provides a significant cognitive challenge (Light and Butterworth 1992). Collaboration is also considered important in providing opportunities for cognitive conflict as efforts are made to reach consensus (Doise and Mugny 1984), and for the co-construction of potential solutions in the creative processes. Arguably, emergent science education provides the greatest curriculum potential for this sort of intellectual engagement.

An 'emergent' science curriculum is a curriculum responsive to children's needs as individuals; it accepts diversity of experience, interests and development. An emergent science curriculum is also a curriculum that respects the power and importance of play and that supports children in becoming more accomplished players, good at choosing, constructing and co-constructing their own learning. To sustain an interest in science is to sustain an interest in problem solving and exploration and for Bandura (1986) these processes begin with imitative learning which are subsequently internalised through identification and incorporated in the individual's self-concept and identity. So the real challenge is to provide children with strong models of science so that they develop positive attitudes and beliefs about the importance of the subject. A good deal of this can be achieved in small group work where children act as a 'collective scientist' under the direction of the adult (Siraj-Blatchford and Macleod-Brudenell 1999). The REPEY research (Siraj-Blatchford *et al.* 2002) found that the cognitive outcomes of the pre-school children whom they studied were directly related to the quantity and quality of the adult planned and focused group work. They also found that the most effective settings achieved a balance between the opportunities provided for children to benefit from teacher-initiated group work and the provision of freely chosen yet potentially instructive play activities.

It would be a nonsense to try to teach literacy by first teaching letter and words in isolation from stories and texts. It is also a nonsense to teach separate science 'skills' without providing a model of investigation. Early years teachers therefore need models, or 'recipes for doing' science if they are to model good scientific practice (Siraj-Blatchford and Macleod-Brudenell 1999). Teachers who teach emergent literacy provide positive role models by showing children the value that they place in their own use of print. In emergent science we can do the same by talking about science and engaging children in collaborative scientific investigations. We can tell the children many of the stories of scientific discovery. In doing so we will encourage children to develop an emergent awareness of the nature and value of the subject as well as positive dispositions towards the science education that they will experience in the future.

Socio-constructivist perspectives in early childhood education (Sayeed and Guerin 2000) recognise the importance of viewing play as an activity where children are developing their confidence and capability for interacting with their cultural environment. If we are to provide for an appropriate, broad and balanced education in the early years we must first think about children playing, but then we must also think about the particular subjects of that play. The clothing we provide for children to dress up in, and the props that we provide for their socio-dramatic play, should include resources to support emergent science. Many classrooms and play areas will already include resources to support playing doctors and nurses and there are usually plenty of resources to support measuring, but more resources need to be made available and I don't think we should be too worried about stereotypes at this age as long as they are not gendered. We might therefore consider providing young children with lab coats, extra large (plastic) test tubes and racks, flasks, burettes and coloured fluids and powders to play at being chemists. Toy manufactures could also do more to provide simple sensing equipment (I describe the Blatchford Buzz Box later in the section on data logging). For some early years practitioners this will all seem too prescriptive, but as Vygotsky (1978: 103) argued, 'In one sense a child at play is free to determine his own actions. But in another sense this is an illusory freedom, for his actions are in fact subordinated to the meanings of things and he acts accordingly.'

Screen-based activities have been shown to support the processes of verbal reflection and abstraction (Forman 1989). This is a theme specifically addressed by Bowman *et al.* (2001: 229) in the US National Research Council's report *Eager to Learn: Educating our Preschoolers*. The report strongly endorses the application of computers in early childhood:

> Computers help even young children think about thinking, as early proponents suggested (Papert 1980). In one study, preschoolers who used computers scored higher on measures of metacognition (Fletcher-Flinn and Suddendorf 1996). They were more able to keep in mind a number of different mental states simultaneously and had more sophisticated theories of mind than those who did not use computers.

The 'example materials' for the Foundation Stage produced for the Primary National Strategy (DfES 2004) provide concrete suggestions on how to use ICT to support the early learning goals within knowledge and understanding of the world:

> ICT resources can help children in 'developing crucial knowledge, skills and understanding that will enable them to make sense of their own,

immediate environment as well as environments of others'. Digital photographs, tape recorders, camcorders and webcams can allow children to investigate living things, objects and materials, some of which might not be accessible otherwise, for example with a webcam placed in a wildlife area.

As previously suggested, we need to begin by considering how this fits into a playful curriculum. In the following pages applications appropriate for supporting science in the Foundation Stage are illustrated under each of the following categories:

- Information sources
  e.g. ICT provides a wide range of resources, including the Internet and CD-ROM encyclopedias to support adults and children.
- Data handling
  e.g. especially providing support for 'counting' and in graphically displaying data from surveys.
- Data logging
  e.g. using sensors to observe changes more clearly.
- Sorting and branching
  e.g. identifying attributes and introducing classification.
- Simulation and modelling
  e.g. to investigate the effects of changing variables.

Play and problem solving

Most developmental psychologists treat play as either one, or some combination of three things:

1. Play as an exploration of the object environment
2. Play as an experience of an experimental and flexible nature, and
3. Play as a facilitator of the transition from concrete to abstract thought.

(Adapted from Pepler 1982)

Exploration in this sense may be considered a necessary preamble to play, or as an initial stage within play. It may represent an integral part or a separate, although closely related, activity. In experimenting, the child moves beyond discovering the properties of objects, to determine what s/he can do with the object. This fits in well with Bruner's notion of 'mastery'. The importance here of the child being left free from the tensions of instrumental goals is often stressed. This allows for more novel, less inhibited, responses and applications of the objects of play. Play provides the opportunity for children to consider objects abstractly and this is an adaptive mechanism that facilitates problem solving. The folded paper that signifies for the child an aeroplane soaring through the sky becomes 'a pivot' for severing the meaning of 'aeroplane' from real aeroplanes. The focus of attention becomes what it is that the object signifies and can do, its properties and functions rather than its representation in the 'real' world. The objects of symbolic play thus provide important precursors for representational thought.

The importance of all this shouldn't be understated; pretend play has a major role in early cognitive development. The symbolisation that begins with objects goes on to be shared with the parent, then with peers and, as Piaget argued, the reciprocity in peer relations provides foundations for perspective taking and decentring. This in turn provides a model for symbolising 'the self' and the 'other' and supports the development of the child's 'theory of mind'. In the circumstances it isn't at all surprising that children's preference for socio-dramatic play has been shown to be correlated with intellectual performance (in terms of both IQ and ability scales).

Sylva *et al.* (1976) showed us that play facilitated problem solving. Divergent thinking is central to both play and creativity and longitudinal studies have also shown that creativity in pretend play is predictive of divergent thinking over time (Russ *et al.* 1999). As Edwards and Hiler (1993) argued in their teacher's guide to 'Reggio Emilia' (which is based in Italy and champions a particular approach to early years education), young children are developmentally capable of all the high-level thinking skills. We should therefore encourage them in their day-to-day practices of analysis (e.g. seeing similarities and differences); synthesis (e.g. rearranging, reorganising); and evaluation (e.g. judging the value of things).

In an evaluation of the Northamptonshire LEA Foundation Stage ICT programme (Siraj-Blatchford and Siraj-Blatchford 2006), we found that, given appropriate training, Reception teachers were able to make enormous progress in expanding the opportunities in their classrooms for play using ICT. In one example, Chrissie Dale, a Reception teacher at King's Sutton School, used Granada's Learning at the Vets software to support science and to encourage emergent writing (Figure 8.1).

> 1.11.04: The children have all been desperate to have a go at this one and demonstrating it on the whiteboard was a very effective way of showing the children how to use the program. However, when trying to use the program on the PC the children needed a lot of support. For each child to have a turn took a long time and has tended to initially interrupt the role play that has been established.
>
> (Chrissie Dale, King's Sutton School)

This application was also developed further to incorporate a Listening Station (Figure 8.2) as an Answer Phone at the vets:

> Some of the children have started pretending to write the messages down but I have not yet observed them taking these messages into their

Figure 8.1 Children working with Learning at the Vets.

play. I need to rerecord the messages as the volume levels are uneven and they need more careful thinking out to vary the play that they might develop. I need to buy a tape with the shortest running time that I can find or might even buy a cheap answering machine or ask parents to donate an old one.

(op cit)

Information sources

The value of taking children out of the classroom to learn from the environment is widely recognised in early education. CD-ROM talking encyclopaedias and the Internet extend the possibilities even further. A wide range of other early learning software is also available. One notable example is Percy's Animal Explorer (Figure 8.3).

Percy is a talking caterpillar who supports the children in learning about different animals and the sounds they make. Other games include finding the odd one out, matching pictures to sounds and learning where the animals live. The locations include a farm, a garden, the jungle and under the sea.

Figure 8.2 A child at the Listening Station.

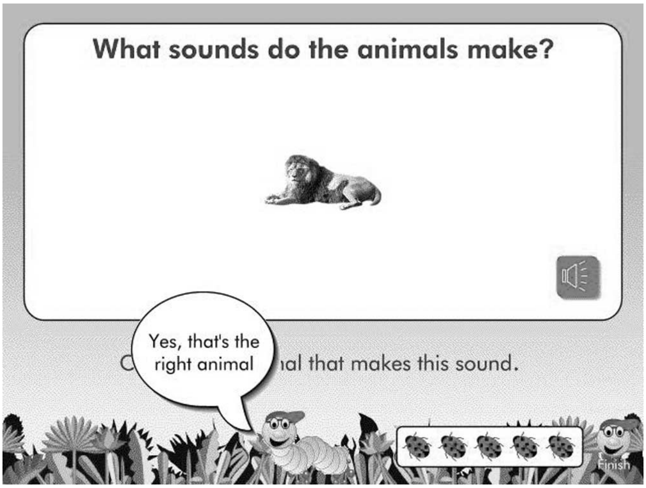
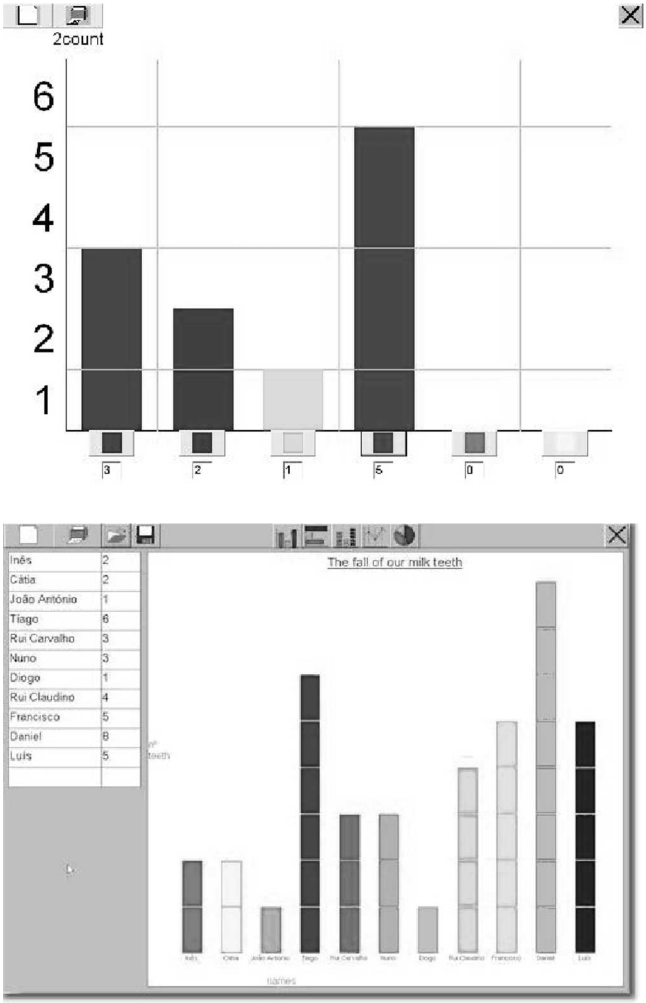


Figure 8.3 Percy's Animal Explorer.

Data handling and display

Many early educators have found that 2Simple's 2Count and 2Graph provides a quick and effective data presentation program that supports children in reflecting upon their data and in answering their questions (Figures 8.4 and 8.5).

Graphs can also be used to summarise information collected over time for analysis, e.g. temperature, type of weather, the growth of a plant, etc.



Figures 8.4 and 8.5 2Simple's 2Graph.

One application developed as a part of the Developmentally Appropriate Technology in Early Childhood (DATEC) project in Portugal (http://datec.org.uk) found that the 2Simple graphs can help the children to summarise and evaluate the data that they collected in different contexts as well as to communicate the information to others. One application involved the children studying their 'baby' teeth falling out. As Folque (2004) has suggested, this was a mathematical activity based on real and affective experiences. The children counted the teeth that they lost and associated this with a sign of their physical development. The experience was also the base for a range of other comparisons, measures and graphing activities. The 2Graph software allowed the children to save different graphs corresponding to different months and to explore each other's progress. The children also explored the different graph layouts in order to find the best one to communicate their central idea.

Data logging

The term 'data logging' may be applied in its broadest sense in the early years to denote all of those resources capable of supporting children in their observations of natural and humanmade phenomena. Early years data-logging resources, therefore, include a wide range of technologies, from digital cameras to technologies developed to support learning in much more discrete areas of the curriculum. One example of the latter is provided by the Blatchford Buzz Box (TTS) (CLEAPSS 2000; Siraj-Blatchford 2000). The Buzz Box provides an extremely sensitive electronic buzzer that will respond to minute current flows with an audible pitch proportionate to the current flowing in the circuit. It therefore provides a safe means of demonstrating the conductivity of the human body and of water. It is especially valuable in teaching young children about basic circuit principles and the dangers of electricity.

An example of a much more flexible data logging resource is provided by the Digital Microscope (Figures 8.6 and 8.7). At Gamesley Early Excellence Centre (Siraj-Blatchford and Siraj-Blatchford 2005) the staff have developed some excellent applications. In terms of the CGFS (QCA 2000), its particular value has been found to support the Knowledge and Understanding of the World and Communication Language and Literacy. A typical example of its use involved the children looking at mini-beasts found in the nursery environment. As the staff at Gamesley – and Feasey *et al.* (2003) – have found, with adult support even the youngest children can benefit from the use of this sort of equipment. Older Foundation Stage children have also been found to be capable of using the microscope independently.

Feasey *et al.* (2003) were commissioned by Becta to evaluate the use of the Intel Play QX3 Computer Microscope which was given to all schools

Figures 8.6 and 8.7 Early years children using a digital microscope, with adult support and alone.

in England as part of Science Year. They found that Foundation Stage children who used the microscope were highly motivated, and particularly keen to discuss their observations. They also found that it was often the children who became the instigators of using the microscope, showing the confidence to explore its potential. The study found that when most teachers and children first learn to use the microscope they cannot resist using it to view parts of their own body, but then they soon move on to discover the great potential that the technology has for supporting work in science, literacy and across the curriculum. Feasey *et al.* observed children using the microscope to view teeth, ears, skin, spiders and woodlice!

In our Northamptonshire ICT evaluation (Siraj-Blatchford and Siraj-Blatchford 2005) we found that digital cameras were being used to support children's reflection, for the purpose of display and documentation and to support communication with parents. At Aldwinkle School, for example, the Reception teacher (Shona Hall) found that the immediacy of the images produced by the digital camera were of immense value in her integrated activity associated with life cycles. The children used the digital camera to record the growth of their sunflowers:

> I believe that the digital camera provided the activity with more focus; because the children were taking their own pictures, they seemed to be looking more carefully for things to photograph. Most could provide an explanation of why they were choosing to take a particular shot and those who could not were given the opportunity to do so when we were viewing the images upon our return to the classroom. Most did this. In this way, I feel that the camera helped to clarify and consolidate the children's learning.
>
> (Shona Hall, Aldwinkle School)

At another Northamptonshire school (All Saints), a digital camera was used to support the children's investigation of bean growth. The children recorded the growth and made up their own 'Bean Diary' to record their findings (Figure 8.8).

> The children loved using the cameras . . . They enjoyed looking at their images after they had taken them and decide whether to re-take or if they were content. The children recorded their own serial numbers of photographs for printing purposes.
>
> (Mia Hobbs, All Saints)

Sorting and branching

Science began when people first recognised patterns. They recognised that there were patterns and regularities in nature that allowed them to

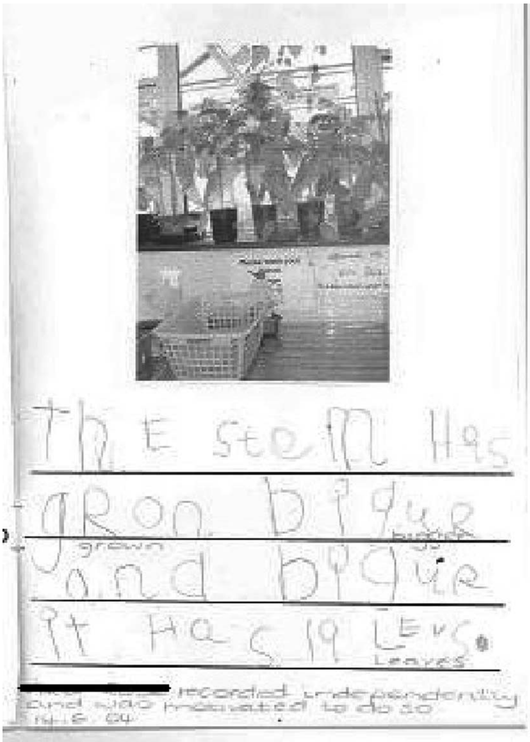


Figure 8.8 Using a digital camera to record a 'bean diary'.

predict the occurrence of natural events in advance. The most spectacular achievement of Thales of Miletus, who is often identified as one of the earliest scientists in Europe, was to predict the eclipse of 585BC.

In *Sammy's Science House: Sorting Station* (Edmark/Riverdeep) children sort pictures into categories, identifying similarities and differences as they begin to learn how plants, animals and minerals are classified (Figure 8.9).

Simulation and modelling

Whilst it presents an American environment, Acorn Pond from *Sammy's Science House* (Edmark/Riverdeep) provides an excellent example of how software can support a visit to a pond for some 'dipping', or other work associated with animal habitats (Figure 8.10). The CD-ROM supports children exploring animal habitats, seasonal changes and the effects of changing variables.

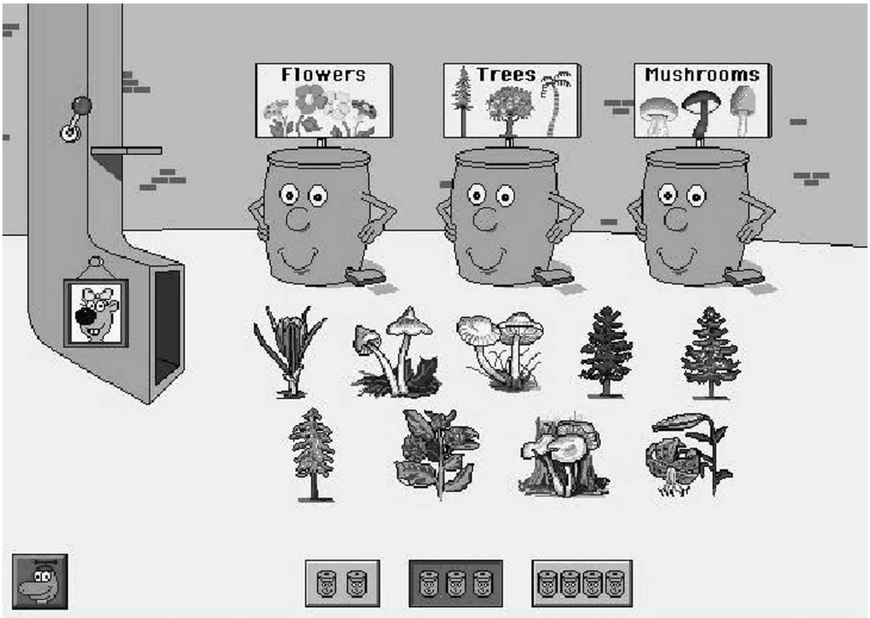


Figure 8.9 *Sammy's Science House: Sorting Station.*

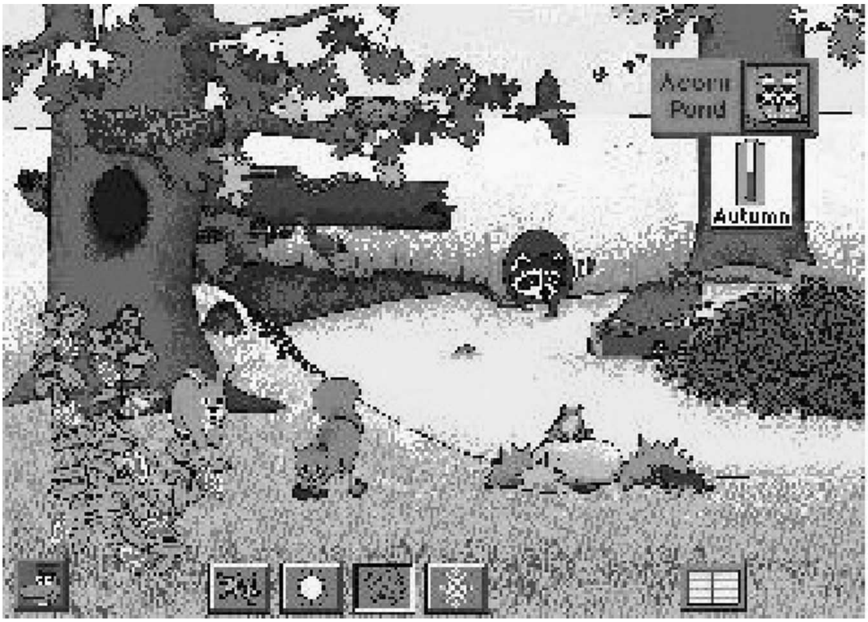


Figure 8.10 Acorn Pond, from *Sammy's Science House*.

Off-computer activities might also include looking at butterfly books, colouring and printing butterfly wing designs. It might also include art work associated with the seasons, investigations of other animal habitats (under rocks, logs etc.), animal tracks and/or physical development sessions where the children 'fly' like butterflies, 'jump' like frogs, 'hop' like rabbits and 'slither' like snakes. *Sammy's Science House* also includes a 'Weather Machine' that allows the children to control the key variables of temperature, moisture and wind. Like a television presenter, Frederick the Bear then reports on the weather (Figure 8.11). The children learn how the changes in the key variables cause changes in weather conditions and also influence the dress and activity of the animated cartoon characters.

With adult support, there are a lot of other simulation and adventure CD-ROMs available that children will benefit from. One excellent example is provided by *Oscar the Balloonist Discovers the Farm* (Tivoli). The story line is described in an Amazon.com review as '. . . something along the lines of Doctor Doolittle meets Monty Python, meets Beatrix Potter'. Oscar tours the world in a hot-air balloon that enables him to travel through the seasons. In this adventure he crash-lands his balloon in a farm and meets an eccentric animal researcher, Balthasar Pumpernickel. In their explorations of the farm environment, children interview the animals and learn about them through a variety of virtual interactions and games. The

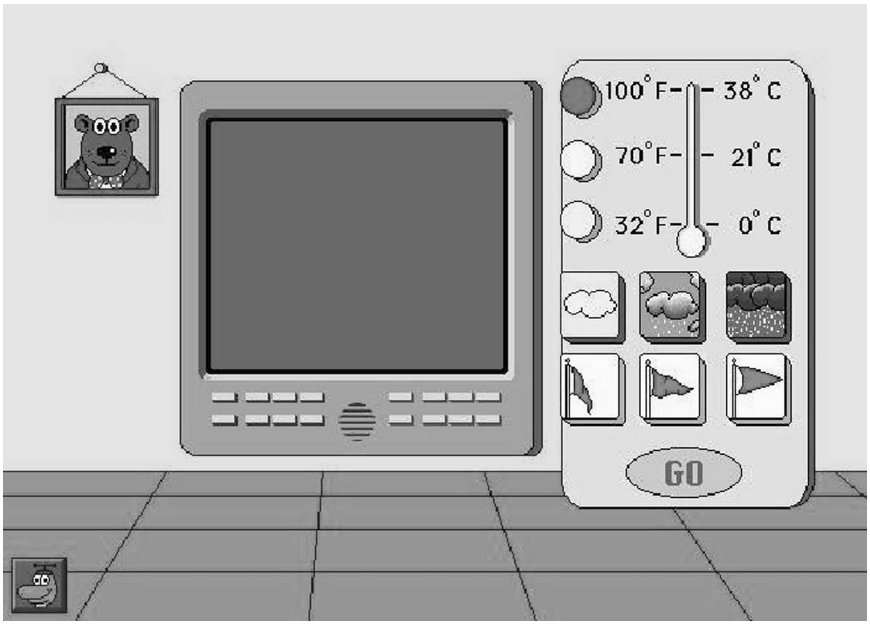


Figure 8.11 Frederick the Bear, also from *Sammy's Science House*.

software also provides a wealth of possibilities for investigations and activities away from the computer. One of the games invites the children to agree or disagree with suggestions such as 'Cows love to eat frogs'! Another title in the Tivoli series is *Oscar the Balloonist and the Secrets of the Forest*. Here, in addition to the changing seasons, the forest environment changes from day to night so that the children meet the nocturnal animals as well. The children will also discover whether squirrels are forgetful, whether ants freeze in the winter and why badgers get fat in autumn.

Conclusions: 'being a scientist'

I have argued that the best way to begin science education is for children to play together and, with adult support, at 'being scientists'. The fact that children in the Foundation Stage are too young to use many ICT applications on their own without adult support shouldn't trouble us at all. 'Science' in any event has never been the product of any individual. As Newton suggested, even the greatest contributions are only made by those 'standing on the shoulders of giants' – and that is just what adults are to young children.

References

Bandura (1986) *Social Foundations of Thought and Action: A Social Cognitive Theory*. Englewood Cliffs, NJ: Prentice Hall.

Bentley, D. and Watts, M. (1994) *Primary Science and Technology*. Buckingham: Open University Press.

Bowman, B., Donovan, S. and Burns, S. (eds) (2001) *Eager to Learn: Educating our Preschoolers*. Washington, DC: Committee on Early Childhood Pedagogy, National Academic Press.

Consortium of Local Education Authorities for the Provision of Science Services (CLEAPSS) (2000) The Blatchford Buzz Box, *Primary Science and Technology Newsletter*, Issue 20, http://www.cleapss.org.uk/priinfr.htm (The Buzz Box is available from: Technology Teaching Systems (TTS) Ltd, http://www.tts-group.co.uk).

de Boo, M. (ed.) (2000) *Science in the Early Years: A Teachers Handbook*. Hatfield: Association for Science Education.

Department for Education and Skills (DfES) (2004) *Learning and Teaching Using ICT: Example Materials from Foundation Stage* (Primary National Strategy/Sure Start CD-ROM) London: HMSO.

Doise, W. and Mugny, G. (1984) *The Social Development of the Intellect*. Oxford: Pergamon Press.

Donaldson, M. (1992) *Human Minds: An Exploration*. London: Penguin Press.

Driver, R. (1985) *The Pupil as Scientist*. Buckingham: Open University Press.

Driver, R., Leach, J. Millar, R. and Scott, P. (1996) *Young People's Images of Science*. Buckingham: Open University Press.

Edwards, A. and Knight, P. (1994) *Effective Early Years Education*. London: Routledge.

Edwards, C.P., and C. Hiler (1993) *A Teacher's Guide to The Exhibit: 'The Hundred Languages Of Children'*, Lexington, KY: College of Human Environmental Sciences, University of Kentucky.

Feasey, R., Gair, J. and Shaw, P. (2003) *Evaluation of the Intel Play QX3 Microscope*. Report to Becta, http://www.becta.org.uk

Fletcher-Flinn, C. and Suddendorf, T. (1996) 'Do computers affect the mind?', *Journal of Educational Computing Research*, 15 (2): 97–112.

Folque, A. (2004) *Graphs*. DATEC, http://www.datec.org.uk

Forman, E. (1989) 'The role of peer interaction in the social construction of mathematical knowledge', *International Journal of Educational Research*, 13: 55–69.

Hodson, D. (1998) *Teaching and Learning Science: Towards a Personalized Approach*. Buckingham: Open University Press.

Hutt, S., Tyler, S., Hutt, C. and Christopherson, H. (1989) *Play, Exploration and Learning*. London: Routledge.

Light, P. and Butterworth, G. (eds) (1992) *Context and Cognition: Ways of Learning and Knowing*. Hemel Hempstead: Harvester Wheatsheaf.

Papert, S. (1981) *Mindstorms: Children, Computers and Powerful Ideas*. New York: Basic Books.

Pepler, D.J. (1982) 'Play and divergent thinking', in Pepler, D.J. and Rubin, H. (eds) *Contributions to Human Development: Vol. 6 – The Play of Children: Current Theory and Research*. Basel: Karger.

Piaget, J. (1969) *Mechanisms of Perception*. London: Routledge and Kegan Paul.

Qualifications and Curriculum Authority/Department for Education and Employment (QCA/DfEE) (1999) *The National Curriculum: Handbook for Primary Teachers in England, Key Stages 1 and 2*. London: HMSO.

QCA/DfEE (2000) *Curriculum Guidance for the Foundation Stage: Stepping Stones*. London: HMSO.

Russ, S., Robins, A. and Christiano, B. (1999) 'Pretend play: longitudinal prediction of creativity and affect in fantasy in children', *Creativity Research Journal*, 12 (2): 129

Siraj-Blatchford, I. and Siraj-Blatchford, J. (2006) *A Guide to Developing the ICT Curriculum for Early Childhood Education*. Stoke-on-Trent: Trentham Books, http://www.trentham-books.co.uk/pages/guidetoict.htm

Siraj-Blatchford, J. (2000) *Nearly 101 Things to Do with a Buzz Box: A Comprehensive Guide to Basic Electricity Education*. Nottingham: SB Publications in association with Education Now Books.

Siraj-Blatchford, J. (2003) *Developing New Technologies for Young Children*. Stoke-on-Trent: Trentham Books.

Siraj-Blatchford, J. and MacLeod-Brudenell, I. (1999) *Supporting Science, Design and Technology in the Early Years*. Buckingham: Open University Press.

Siraj-Blatchford, J. and Siraj-Blatchford, I. (1998) 'Learning through making in the early years', in Smith, J. and Norman, E. (eds) *International Design and Technology Educational Research and Curriculum Development*. Loughborough: Loughborough University of Technology.

Siraj-Blatchford, J. and Siraj-Blatchford, I. (2002a) 'Discriminating between schemes and schemata in young children's emergent learning of science and technology', *International Journal of Early Years Education*, 10 (3).

Siraj-Blatchford, J. and Siraj-Blatchford, I. (2002b) 'Developmentally appropriate technology in early childhood: "video conferencing",' *Contemporary Issues in early Childhood*, 3 (2): 216–225.

Siraj-Blatchford, J. and Siraj-Blatchford, I. (2002c) *IBM KidSmart Early Learning Programme: UK Evaluation Report – Phase 1 (2000–2001)*. London: IBM.

Siraj-Blatchford, J. and Siraj-Blatchford, I. (2003) *A Curriculum Development Guide to ICT in Early Childhood Education*. Stoke-on-Trent: Trentham Books (published in collaboration with Early Education).

Siraj-Blatchford, J. and Whitebread, D. (2003) *Supporting Information and Communications Technology Education in Early Childhood*. Buckingham: Open University Press.

Siraj-Blatchford, I., Sylva, K., Muttock, S., Gilden, R. and Bell, D. (2002) *Effective Pedagogy in the Early Years: Research Report 356*. London: DfES.

Sayeed, Z. and Guerin, E. (2000) *Early Years Play*. London: David Fulton.

Sylva, K., Bruner, J.S. and Genova, P. (1976). 'The role of play in the problem-solving of children 3–5 years old', in Bruner, J., Jolly, A. and Sylva, K. (eds) *Play: Its Role in Evolution and Development*. New York: Basic Books.

Sylva, K., Melhuish, E., Sammons, P., Siraj-Blatchford, I. and Taggart, B. (2000) 'Effective Provision of Pre-school Education project – recent findings'. Presented at the British Educational Research Conference, Cardiff University, September 2000.

Sylva, K., Melhuish, E.C., Sammons, P., Siraj-Blatchford, I. and Taggart, B. (2004) *The Effective Provision of Pre-School Education (EPPE) Project: Technical Paper 12 – The Final Report: Effective Pre-School Education*. London: DfES/Institute of Education, University of London.

Vygotsky, L. (1978) *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

9

USING ICT TO SUPPORT SCIENCE LEARNING OUT OF THE CLASSROOM

Nick Easingwood and John Williams

Introduction

Society in general, and children in particular, are becoming increasingly reliant upon 'virtual', rather than 'real' environments, both for entertainment and education. The latter unquestionably provide opportunities to develop the key scientific skills, based as they are on first-hand experiences of observation, hypothesis and recording; however, these could easily become lost in the virtual world. Although it could be argued that the use of new technologies as an integral part of scientific investigation negates the need for 'old and traditional' scientific investigative skills, the fact remains that practical, first-hand experience is crucially important in good primary science and primary practice in general (DfES 2003a; Chapter 3 in this volume). The key for teachers is to use new technology, and their pupils' sophistication in exploiting its power, to enhance the learning experience.

This chapter will examine how ICT can be used to support learning in 'out-of-school' contexts, focusing on some of the oldest scientific learning environments of all – museums. Because ICT provides interactivity, functionality, personalisation, speed, automation and instant feedback, it enables pupils to gain so much more from a museum visit than they might have done previously. Thus, we will review ideas about learning in museums, exemplify how a museum visit can enhance pupils' learning of primary science, suggest how ICT can enhance pupils' learning in a museum and examine and suggest how digital imaging can be used to enhance pupils' learning of primary science in a museum context.

Learning in museums

It seems clear to us that the focused use of a museum, in which a teacher helps pupils to learn by encouraging them to interact with exhibits in a structured and directed way, can provide a range of learning experiences that simply cannot be simulated accurately or meaningfully elsewhere. Indeed, Howard Gardner recommended that all children engage in museum learning, as it has considerable scope to stimulate their 'multiple intelligences' (Hawkey 2004). Museum learning also has the potential to break down some ideas about teaching and learning that are sometimes associated with schools by those who are not involved in education – namely, that learning must be constrained by a curriculum; that it is a simple acquisition of facts and skills; and that it involves transmission of knowledge from teacher to pupil. Museum educators – to some extent historically (*sic*) free from public scrutiny – have been at liberty to develop their ideas about learning and to engage in alternative approaches (Anderson 1999; MLA 2004). In so doing, many have been strongly influenced by the ideas set out below and drawn from Hawkey (2004).

Hawkey (2001) summarised how thinking about learning has been influential in enhancing museum learning opportunities. Bloom's (1984) *Taxonomy* suggests that learning may occur in any or all of three domains: cognitive, psycho-motor or affective. The cognitive domain is divided into several levels, the lowest of which is factual recall. Appreciating the low level of simple fact presentation has provided museum educators with an impetus to diversify their approach to learning. Gammon (2001) suggested a taxonomy into which museum learning experiences in particular could fall: cognitive, affective, social, skills development and personal. Hooper-Greenhill *et al.* (2003) established a similar taxonomy including the following categories: (a) knowledge and understanding, (b) skills, (c) values and attitudes, (d) enjoyment, inspiration and creativity, and (e) activity, behaviour and progression. These two analyses bear some relation to Gardner's multiple intelligences.

Wider definitions of learning and attempts to describe the learning process sequentially have also been useful. Sharples (2003) described learning as construction of understanding, relating new experiences to existing knowledge. Kolb (1984) attempted to develop such ideas by defining a model of experiential learning, which examines four components of a cycle of learning: immersion in concrete experience, observations and reflections, logical or inductive formation of abstract concepts and generalisations, and empirical testing of the implications of concepts in new situations. He suggested that learners often have strengths in particular components of this cycle, and defined learning styles (accommodator, assimilator, converger and diverger) accordingly. Serrell (1996) identified types of museum learning activities, and the outcomes to those activities, preferred and looked for respectively, by individuals with these learning styles. (Table 9.1)

Table 9.1 Learning styles and preferred activities and outcomes (Serrell 1996)

Learning style	*Preferred activities*	*Outcome sought*
Accommodator	Imaginative Trial and error	Hidden meaning
Assimilator	Interpretation that provides facts and sequential ideas	Intellectual comprehension
Converger	Try out theories	Solutions to problems
Diverger	Interpretation that encourages social interaction	Personal meaning

Given the increasing focus on classifying learning styles as visual, auditory and kinaesthetic (e.g. DfES 2003b), there appear to be intuitive and obvious ways in which museum experiences may target students with such styles. For example, the range of visual and 'hands-on' opportunities that could be offered within a museum would appear to appeal to pupils with kinaesthetic and visual styles (Stephenson and Sword 2004). It should be recognised that controversy exists about the applicability and reliability of the range of learning style models.

Another productive approach is to distinguish between theories of learning and theories of knowledge (Hein 1995, 1998), and to keep those classifications in mind when designing learning opportunities:

- Views of knowledge exist on a continuum, the extremes of which are:
  - knowledge is absolute truth
  - knowledge is the creation of the human mind.
- Views of learning exist on a continuum, the extremes of which are:
  - learning is passive with museums' purpose to pour learning into an 'empty vessel' of the mind
  - learning is actively assimilated into existing cognitive structures by the learner.

Table 9.2 shows the four ways in which these views of learning and knowledge can combine to yield four domains of learning.

Table 9.2 Domains of knowledge and learning

Domain	*Knowledge*	*Learning*
Didactic	Knowledge is absolute truth	Learning is passive
Heuristic	Knowledge is absolute truth	Learning is constructed from ideas and experience
Constructivist	Knowledge is constructed	Learning is constructed from ideas and experience
Behaviourist	Knowledge is constructed	Learning is passive

To design museum learning opportunities that respond to the ideas above cannot be done using a 'one size fits all' model. Learning from, rather than about, objects, providing the opportunity for a variety of active and enquiry-based learning activities – and structuring and coordinating a range of meaningful learning choices within a particular context – are essential components for success (Hawkey 2004; Johnson and Quinn 2004). Provision of motivating learning experiences that are stimulating, enjoyable and relevant is essential. Embedding such experiences in the interdisciplinary approach facilitated by museums is also more likely to enable pupils to make links between areas of learning (Hawkey 2004).

How can a museum visit enhance pupils' learning of primary science?

A recent case study shows very effectively how the ideas outlined above enabled primary pupils' learning of science during a museum-based investigation (OFSTED 2003; Stephenson and Sword 2004). This investigation concerned the challenges facing ancient civilisations and was cross-curricular, drawing upon science, history, and design and technology. The museum work involved unravelling the story of the granite sarcophagus of Rameses III in the Fitzwilliam Museum at the University of Cambridge. This was followed up with classroom-based investigations, which allowed pupils to test hypotheses developed in the museum.

Stephenson and Sword (2004) found that the museum experience can encourage pupils to think autonomously about science with versatility, imagination, individual creativity and tenacity. Their activity enhanced motivation, and encouraged the development of sophisticated information processing skills (OFSTED 2003). The museum's enhanced funding, by comparison to primary schools, enabled pupils to have access to appropriate authentic materials (inspiring 'awe and wonder'), which appeared to give learning more meaning, particularly as the tasks were situated within a contextualised cross-curricular approach with which pupils could empathise. By using open-ended problem solving, pupils were enabled to engage with learning at a level appropriate to them, facilitating differentiation. In the museum, pupils seemed less likely to pre-judge the 'correct' answer to investigations and to immerse themselves in the learning context.

Structuring the opportunity for focused discussion around museum artefacts, as part of a 'journey of enquiry' (OFSTED 2003) was key to facilitating learning. This 'journey' encouraged pupils to ask questions of those objects in relation to problem solving scenarios that required comparison and close observation, fostering learning and providing the opportunity for development of pupils' creativity. By exploiting the museum's own science educators and practitioners, pupils had access to specialists and specialist information, which could extend their discussions to broaden and deepen their learning.

Pupils' scientific principles and skills were also developed. In the museum, pupils had to search for evidence to support or refute their hypothesis. In the classroom, pupils subsequently carried out investigations, which were still 'situated' within the contexts developed in the museum. Across both locations, they were asked to think creatively to explain how things worked, to test and refine their ideas in the classroom and museum, to present their ideas to their peers and to interrogate each others' solutions; this developed their skills of reflection and evaluation and helped them to review their own learning. The group work involved in the whole process gave ample opportunity to assess pupils' learning.

How can ICT enhance pupils' learning in a museum context?

Museums have had a dual role in scholarship and education since their inception. These two roles have come together in recent years and this fusion is being facilitated by ICT, which is increasingly being used to enhance learning, both of schoolchildren and of lifelong learners (Hawkey 2004).

Of course, the lifeblood of the educative role of museums has traditionally been exhibited objects. Such artefacts can be awe-inspiring (such as the *Flying Scotsman*); alternatively they can challenge visitors to compare and contrast reality with popular image. For example, the popular image of George Stephenson's *Rocket* is of a large, yellow locomotive; yet modern-day visitors to the exhibit in the Science Museum in London will see a small, black locomotive, with a very rough iron outer casing.

ICT can enhance learning from such artefacts, both by facilitating and accelerating traditional learning approaches, but also by expanding the range of learning experiences available (Hawkey 2004). Museum education officers have increasingly tried to design exhibitions and experiences based upon defined learning objectives, interactivity, learner participation and collaboration, and the facilitation of learner initiative in interacting with exhibits. Although this has taken place both with and without the aid of ICT, ICT has certainly facilitated the process, and has helped to develop museums as places of exploration and discovery (Hawkey 2004). In fact, ICT may have become so pervasive so quickly in museum education because learning from museums and learning from digital technologies, share many of the same attributes, including learning from objects, rather than about them, and developing strategies for discovering information, rather than being presented with the information itself (Hawkey 2004).

ICT has considerable power to enable pupils' learning in museums because it can facilitate interactivity and participation, collaboration between learners (both onsite and online) to construct ideas and the personalisation of learning experiences to account for prior knowledge and learners' preferences (Hein 1990; Hawkey 2004); it may also exploit mobile technologies (Naismith *et al.* 2004). For example, personalisation of pupils' experiences may begin even before they reach the museum. Even using the museum's website (including maps, gallery information and virtual tours) to help plan their route around the museum, in response to activities suggested by the teacher, gives pupils immediate autonomy and enables them to make choices about their learning in the museum. However, other technology may also benefit learning in the museum context, including still and moving images (video and animations), simulations and presentations, games, and the increasing use of the Internet and the museums' own intranets (Littlejohn and Higginson 2003). Of these, the use of digital imaging appears to have very considerable potential.

How can digital imaging enhance pupils' learning of primary science within a museum context?

It is almost part of folklore that, in the past, pupils had to make a written description of every educational visit, with such writing often containing little reflection or analysis upon what had been seen. Although creative and imaginative teachers have always found alternative means of getting children to analyse, record and report educational visits, ICT can bring new opportunities that were largely unimaginable ten years ago. Central to this is the use of digital imaging.

Still images

Effective use of 'still' images must start with appreciation that the original capturing of the image or taking the photograph is no longer the end of the process, but the beginning of it. From here the images can be inserted into different types of applications; for example, they may be used in a multimedia presentation or web page, where children can point and click on hyperlinks to link to another slide. This means that information is not presented in a linear way, which in turn means that an element of creativity and imagination has to be employed by the designer and an element of choice by the user. Unsurprisingly, it is important for pupils to take account of their audience when designing such a website or presentation.

The STEM project at the Science Museum in London worked with primary pupils to help them design a website, based around their museum visit, which exploited digital images in this way. The children designing the website had to be able to analyse and synthesise what they had seen in order to present ideas in a manageable form and users commonly needed to be able to think laterally in order to exercise an element of choice. This means that both designer and user have to exercise higher-order thinking skills, an immediate validation of the use of ICT in this context. Previously the 'designer' would have written a simple report or description of what had been seen and the user would have simply read what was written. However, the use of web-page design or multimedia presentation ensures there is interactivity and engagement with both roles.

Much presentation software also enables further functionality to add to pupils' analysis and teachers' assessment of their learning. Examples include the embellishment and annotation of images by the use of callouts (speech bubbles) and draw tools and the embellishment of reports as a whole by the addition of a commentary, which itself could be recorded by the pupils in the museum.

Video images

Digital video is video that can be stored, manipulated and edited on computer. Digital video cameras can record museum experiences more effectively than still cameras and have advantages over analogue video cameras (Becta 2003) for the following reasons:

- digital cameras are smaller and lighter than VHS cameras, facilitating their use in a mobile museum context;
- picture quality is enhanced;
- digital video is easy to edit, enabling students to produce high-quality films in a short time;
- digital video can be integrated with other forms of technology, such as presentation software and the Internet.

Because digital video editing software is now so accessible and ubiquitous (for example, iMovie and Windows Movie Maker are both free with Mac and Windows operating systems respectively), primary school pupils now have access to functionality that until recently was restricted to professional television and film makers. This means that a child can video aspects of a museum visit, or indeed any 'out-of-school' work, and on returning to school can download the recorded 'footage' into a computer and then edit the movie into a manageable form for viewing. This could include adding a soundtrack such as narration, music and sound effects, as well as titles and transitions between clips. By dragging, cutting, copying and pasting into a storyboard at the bottom of the screen, children can edit and create a complete film in the same way that they can edit a piece of word-processed text. This flexibility means that the video can subsequently be used in similar ways to those images captured with a 'still' camera, as described above.

Making digital videos centred on museum visits appears particularly suited to enabling pupils' learning because many of the learning opportunities provided mirror – to some extent – those of the museum itself (Becta 2003). Digital video lends itself to cross-curricular activities (Becta 2004), facilitating the interdisciplinary approach highlighted as important earlier and exemplified in the case study (Stephenson and Sword 2004). Making digital videos can enhance motivation, enjoyment and self-esteem (Burn and Reed 1999; Ryan 2002), is more likely to draw on pupils' out-of-school interests (Parker 2002) and can enable self-expression and creativity (Becta 2002). Its motivational effects are exemplified by the length of extra time spent on digital video projects by students. Digital video also enables differentiation according to students' learning styles and attainment levels (Burn and Reed 1999) and removes literacy difficulties as an obstacle to learning. For example, rather than capturing and analysing data on paper, or recording their museum visit through words, pupils can now make simple records using moving images (Becta 2002, 2003). The process of working collaboratively in groups to produce and edit digital video encourages learning through discussion and problem-solving (Becta 2002) and encourages children to think about their learning (Swain *et al.* 2003). The flexibility afforded by digital video software and its timeline also allows students to draft and redraft sequences quickly and easily, encouraging creative experimentation (Buckingham *et al.* 1999; Burn and Reed 1999), and developing understanding of narrative and structuring of scientific argument (Becta 2002).

Despite the value that making a video may have for pupils' learning, the audience to the final product will usually take on the role of a passive viewer with little opportunity for interaction. Although still useful, enabling interactive engagement with the video can also help to maximise the learning of the viewer. For example, when inserted into a presentation, the user must point and click to select a video clip. The nature of this type of activity will mean that the clips will be shorter, and the investigative skills developed will engage the viewer with the material throughout, maintaining concentration more effectively.

To use digital video successfully within a museum visit will require planning and preparation by the teacher (Becta 2002). Hardware issues include the requirement to have modern computers with high-capacity hard drives and fast processing speeds (Yao and Ouyang 2001), enough digital video cameras for each group in the class and the facility to save products to external media, such as CD or DVD writers or USB memory sticks. Frequency of use by pupils is important, particularly if a specific subject focus is to be emphasised (Becta 2002), and the skills required to use the cameras effectively and edit the product clearly need to be taught. This might involve the addition of titles, soundtracks, fades in and out and special effects. Elements of production are also important. As the children become more familiar with the art of movie making, they will learn how to create movies that engage and keep the viewer interested, e.g. by using several different camera angles or 'cut-aways'. There is evidence that making a film for an audience, such as parents or peers, maximises the benefits to motivation and self-esteem (Buckingham *et al.* 1999). It is also important to ensure that the children record short clips of just a few seconds. This is because it is easier to edit short clips than longer ones and it will reduce download times. Key teaching questions include: 'Why are you recording that?' and 'How do you hope that it will fit with your final presentation?'

Exploiting the benefits of digital video in the context of museum learning of primary science requires a structured approach by the teacher. The stages of implementation include:

1. preparation, which is likely to occur before the visit;
2. identifying an audience;
3. producing storyboards and flowcharts;
4. making the film at the museum;
5. editing the film in school;
6. showing the film or using it as part of a presentation.

Evaluation of the outcomes by peers is an important part of the learning process (Becta 2003).

If we take primary science to include not only scientific observation and experimentation, but also aspects of role play and drama, then we can include not only the historical artefacts in the museum itself but also the scientists and engineers that first discovered or invented them. For example, in the past, personalities such as 'Doctor Who' have been used to take the audience back through time to meet such notables as Galileo, Newton, Faraday and Darwin (Williams 2000). Providing pupils with the opportunity to use museum websites to plan their approach to the science, to storyboard such a drama prior to the visit and then to use the museum for filming 'in role' and 'in situ' provides an excellent foundation for learning.

Another important example addresses the need to encourage and develop children's investigative skills. Many museums now have interactive investigative galleries aimed directly at school pupils. A good example of this would be Launch Pad in the Science Museum in London. Using digital video and other relevant ICT to record quantitative and qualitative results of investigations enables pupils and teachers to exploit the learning benefits outlined above and to provide a springboard for further learning. For example, during the case study of Stephenson and Sword (2004), pupils could have used digital video to record information collected in the museum, and then to produce a film of the whole investigative process. Again, as with any use of ICT, it is essential in this example to provide pupils with tightly focused tasks, which stem from tightly structured prior preparation in school and from regular progress reviews. Expecting pupils to arrive at a museum to record a digital video 'ad-hoc' is misguided and a waste of an effective learning opportunity.

Concluding and looking forward

Using digital imaging to record a museum visit enables pupils to learn during the visit, provides a record of what they saw after the visit and gives further opportunities for follow-up learning back in school. Such benefits would apply to other educational visits as well. Of course, the museum will often have its own website, or may produce a CD-ROM which can be used in the same way, but whatever type of ICT is used it is important to remember that all of the ICT mentioned in this chapter is relatively easy to use. Although time would be required to learn how to use the hardware and software, such skills can subsequently be reinforced and extended in much the same way as the other skills that a child learns and develops during the primary phase. This is a sound investment of time and resources. Combination of these new technologies alongside the oldest and most traditional of scientific environments, by an imaginative and creative teacher, can access levels of learning previously unimaginable.

So what opportunities will be available for exploitation by creative primary science teachers in the museums of the future? Mobile resources appear to have considerable potential to enhance personalisation and interaction in the way that visitors learn from museums. Indeed, the functionality of PDAs, mobile phones and digital cameras are already beginning to overlap and mobile resources of the future are likely to have ever-increasing computing power, enabling fully functional interaction with the Internet and access to communication networks, on the move. The integration of 'context-aware' functionality in mobile devices, which provides information to users according to their location, is becoming increasingly visible in museums and other centres of 'informal' learning, enabling some personalisation and direction to a visitor's learning experience and enhancing the exploitation of novel learning experiences such as augmented reality gaming (Naismith *et al.* 2004). The ability to interact and collaborate both with other visitors (such as classmates in the museum) and extended groups of learners across more and more extensive learning networks (such as classmates back at school, or with pupils from other schools) is also ripe for exploitation (Naismith *et al.* 2004; Chapter 10 in this volume). Pupils are also likely to see an increase in what are becoming known as tangible technologies, part of the ubiquitous computing vision (Weiser 1991) in which technology becomes part of the environment and within which inputs (which conventionally were made via a mouse or a keyboard) become more physical, and more closely tied to outputs. Examples could include augmented museum displays, in which a soundtrack is initiated by moving a hand over some text, or simply by moving towards an exhibit; or exhibits in which visitors can manipulate physical objects to have a digital effect, for example on a simulation (O'Malley and Stanton Fraser 2005).

This chapter began with a statement about the importance of first-hand scientific experience for all pupils. We have described in detail the benefits of digital imaging, and examined some of the opportunities provided by ICT in museum education, but perhaps we should now remind ourselves of the primary reason for a museum visit. It is by visiting museums that most children will have direct contact with science and with the science that has led to the technological advances associated with the rise of numerous civilisations. Museums have changed considerably over the years. Not so long ago they were just collections of artefacts, models and specimens. Indeed, we still remember the first 'hands-on' exhibits, which caused much excitement because for the first time children could actually work machines, or by pressing a button actually observe some biological processes in action. Since then we have had specially designed ecological galleries which show the specimens in their natural environment. Today, we even have a dinosaur that moves (but only from side to side) and makes sounds (which are rather unlikely to be authentic!). Although more and more museums have become far more engaging, the balance between learning and entertainment may still need refining, and the work of Stephenson and Sword (2004) makes clear the very great continuing potential for developing science activity and engagement in 'traditional' museums. In all cases, however, the way in which teachers and museum educators exploit ICT will be a key feature in getting that balance right.

References

Anderson, D. (1999) *A Common Wealth: Museums in the Learning Age*. London: Department of Culture, Media and Sport.

Becta (2002) *Evaluation Report of the BECTA Digital Video Pilot Project*. Coventry: Becta.

Becta (2003) *What the Research Says about Digital Video in Teaching and Learning*. Coventry: Becta.

Becta (2004) *Using Digital Video Assets Across the Curriculum (CD)*. Coventry: Becta.

Bloom, B.S. (1984) *Taxonomy of Educational Objectives*. Boston, MA: Allyn and Bacon.

Buckingham, D., Harvey, I., Sefton-Green, J. (1999) 'The difference is digital. Digital technology and student media production', *Convergence*, 5: 10–20.

Burn, A. and Reed, K. (1999) 'Digi-teens: media literacies and digital technologies in the secondary classroom', *English in Education*, 33: 5–20.

Department for Education and Skills (DfES) (2003a) *Excellence and Enjoyment: A Strategy for Primary Schools*. London: HMSO.

DFES (2003b) *Conditions for Learning 10: Learning Styles*. London: HMSO.

DfES (2004) *Excellence and Enjoyment: Learning and Teaching in the Primary Years: Understanding How Learning Develops*. London: HMSO.

Gammon, B. (2001) *Assessing Learning in Museum Environments: A Practical Guide for Museum Educators*. London: Science Museum.

Hawkey, R. (2001) 'Innovation, inspiration, interpretation: museums, science and learning', *Ways of Knowing Journal*, 1 (1): 23–31.

Hawkey, R. (2004) *Report 9: Learning with Digital Technologies in Museums, Science Centres and Galleries*. Bristol: NESTA Futurelab.

Hein, G. (1995) The constructivist museum, *Journal for Education in Museums*, 16: 21–23.

Hein, G. (1998) *Learning in the Museum*. London: Routledge.

Hein, H. (1990) *The Exploratorium: The Museum as Laboratory*. Washington: Smithsonian Institution Press.

Hooper-Greenhill, E., Dodd, J., Moussouri, R. *et al*. (2003) 'Measuring the outcomes and impact of learning in museums, archives and libraries'. End of project paper for the Learning Impact and Research Project. Leicester: Research Centre for Museums and Galleries.

Johnson, C. and Quin, M. (2004) *Learning in Science and Discovery Centres; Science Centre Impact Study*. Washington: ASTC.

Kolb, D.A. (1984) *Experiential Learning*. Englewood Cliffs, NJ: Prentice Hall.

Littlejohn, A. and Higginson, C. (2003) *A Guide for Teachers (e-learning series number 3)*. London: Learning and Teaching Support Network.

MLA (Museums, Libraries and Archives Council) (2004) *Inspiring Learning for All*. London: MLA.

Naismith, L., Lonsdale, P., Vavoula, G. and Sharples, M. (2004) *Report 11: Literature Review in Mobile Technologies and Learning*. Bristol: NESTA Futurelab.

Office for Standards in Education (OFSTED) (2003) *Expecting the Unexpected: Learning and Teaching in the Primary Years*. London: HMSO.

O'Malley, C. and Stanton Fraser, D. (2005) *Report 12: Literature Review in Learning with Tangible Technologies*. Bristol: NESTA Futurelab.

Parker, D. (2002) 'Show us a story: an overview of recent research and resource development work at the British Film Institute', *English in Education*, 36: 38–44.

Ryan, S. (2002) 'Digital video: using technology to improve learner motivation', *Modern English Teacher*, 11: 72–75.

Serrell, B. (1996) *Exhibit Labels: An Interpretive Approach*. Lanham, MD: Altamira Press.

Sharples, M. (2003) 'Disruptive devices: mobile technology for conversational learning', *International Journal of Continuing Engineering Education and Lifelong Learning*, 12: 504–520.

Stephenson, P. and Sword, F. (2004) 'The ancients' appliance of science', *Primary Science Review*, 84: 22–25.

Swain, C., Sharpe, R. and Dawson, K. (2003) 'Using digital video to study history', *Social Education*, 69: 154–157.

Weiser, M. (1991) The computer for the 21st century, *Scientific American*, 265: 94–104.

Williams, J. (2000) 'Galileo after the trial: a short play', *Breakthrough*, 2 (3).

Williams, J. and Easingwood, N. (eds) (2003) *ICT and Primary Science*. London: Routledge Falmer.

Williams, J. and Easingwood, N. (2006) 'Possibilities and practicalities – planning, teaching, and learning science with ICT', in Warwick, P., Wilson, E. and Winterbottom, M. (eds) *Teaching and Learning Primary Science with ICT.* Maidenhead: Open University Press.

Yao, J.E. and Ouyang, J.R. (2001) 'Digital video: what should teachers know?' Paper presented to the Society for Information Technology and Teacher Education International Conference.

10

VIRTUAL LEARNING IN PRIMARY SCIENCE

Helena Gillespie

Introduction

Since the mid-1980s the Internet has been connected with science teaching and learning. Originally the invention of professional scientists, the Internet was first used to communicate findings and ideas. Since then, its use in teaching and learning in schools has become common in all phases and subjects. Some would argue that the future of education will continue to be substantially affected by what the Internet can do.

However, the case for computer use in general, and Internet use in particular, has yet to convince some teachers and educationalists. Substantial funds have been invested in ICT in schools over the past few years (in UK schools, the total investment for 2005/06 is in the region of £700 million). Despite this investment, some studies (Harrison *et al.* 2002) have pointed to the difficulty of finding clear and conclusive evidence that ICT can enhance teaching and learning.

It is increasingly clear, however, that teachers, teacher trainers, academics, administrators, advisory teachers and members of government believe that computers can positively affect teaching and learning. In 2004, Charles Clarke, then Secretary of State for education in the UK, asserted that although the 'potential for transformation remains largely untapped', ICT can 'undoubtedly' be beneficial for education (DfES 2003). This chapter will examine what this potential for transformation might be in the context of virtual learning environments (VLEs) and how the transformation might take place in primary science education.

In 2005 the Joint Information Systems Committee (JISC) set out their requirements for a VLE. Elements include a mapped curriculum, based on some sort of electronically delivered content, with the ability to track student activity with a communications system. However, whether this is a comprehensive and universal description is open to question. In essence, a VLE is a place where learning takes place via the Internet. It is different from a web page because it brings together resources, allows communication and has the tools to enable teachers to track how the resources are being used.

Very few primary schools are currently using VLEs, although they are widespread in higher and further education and are becoming increasingly common in secondary education. The intention of this chapter is to look to the future and to examine the potential of VLE use in primary schools, drawing upon what we have learnt about VLEs from their use in higher and secondary education. The 'real transformation' (DfES 2003) should be to the benefit of real, authentic, meaningful primary science teaching and learning.

Identifying the potential of virtual learning environments

Since the end of the 1990s, there have been a number of enthusiasts who have suggested ways to bring together content and communication electronically, not only to support traditional face-to-face pedagogies, but to enable new types of learning to take place over the Internet (Laurillard 2002; Pittinsky 2002; Salmon 2004).

Laurillard (2002) champions an approach to learning technology which begins with a consideration of how students learn best. A 'conversational framework' should be constructed using the technology to support learning. Laurillard (2002) also considers the different media of teaching, which she calls narrative, interactive, adaptive, communicative and productive. In this way, the process of learning becomes central to the potential for the use of technology in the classroom.

In *The Wired Tower*, Pittinsky (2002) sets out the pedagogical, theoretical and economic case for the use of VLEs in higher education. In particular, the idea that higher education can be delivered effectively by the 'brick and click' method advocated by Levine (Pittinsky 2002) supports the theory that virtual learning can be delivered alongside traditional learning in a single programme.

Salmon (2004) developed an approach to teaching and learning using VLEs which she calls e-moderating. This is the bringing together of online databases (such as library catalogues and archives), digital teaching materials and communications – either synchronous (happening at the same time) or asynchronous (happening in the same place but at different times). Her ideas about how these elements might combine is exemplified as a '5-stage model' (Figure 10.1), where access to and motivation to use a VLE lead to online socialisation and information exchange and then to knowledge construction and further development. In this way Salmon shows how online learning can be truly interactive and enable learners to develop new ideas.

The enthusiasm of these leaders in virtual learning is grounded firmly in pedagogical thinking. Rather than developing technology for its own sake, such thinking is likely to continue to have the greatest impact on development of VLE usage in higher, secondary and primary education.

Exploiting the potential of virtual learning environments

A recent literature review (Becta 2003a) outlines the stage of VLE development throughout education. In the higher education sector VLEs are

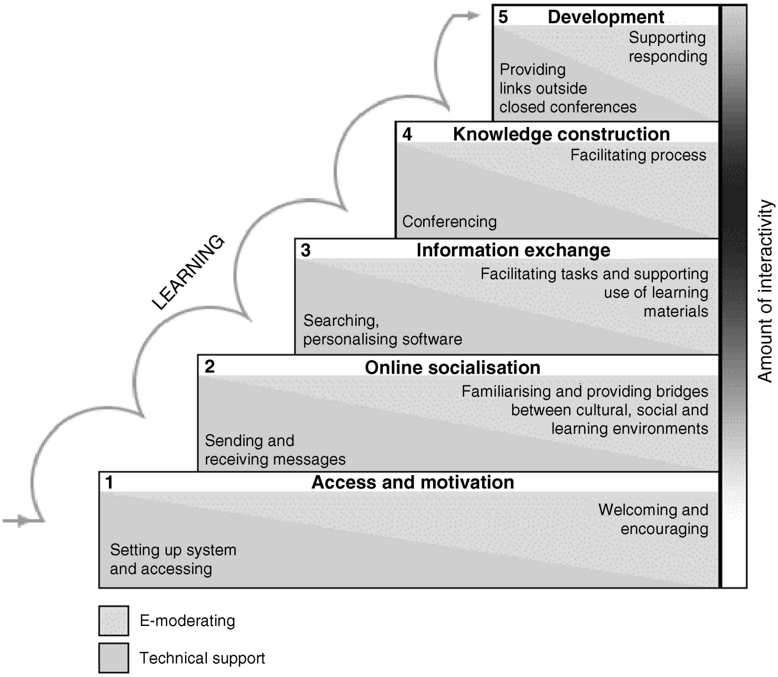


Figure 10.1 Salmon's 5-stage model of e-moderating (Salmon 2004).

now reasonably common. Some institutions have bought 'off the peg' solutions and others have introduced their own in-house solutions. JISC is funding developments in this area, transferring from VLEs to MLEs (managed learning environments), where the VLE works in a connected way with other in-house data and systems such as the student database and library services, through a single portal. In a study of MLE activity in further and higher education (JISC 2002) significant levels of MLE development activity were evident in all the institutions in the survey, with four in five further and higher education institutions using a VLE.

The Becta report on VLEs describes the VLEs in the schools sector as both immature and volatile (Becta 2003a). At the time of writing, research about VLEs at the level of compulsory education was very limited and inconsistent, but recent developments in the broadband network, along with the work of Regional Broadband Consortia, have begun to give UK schools access to VLE technology. However, there is still some work to be done before the available technology becomes successfully embedded in the pedagogical approach of schools. This is most likely to happen in the secondary sector first, where the text-based nature of VLEs is likely to be more appropriate for learners and where schools have the dedicated ICT personnel necessary to drive forward such innovations.

By contrast, VLEs are rare in primary schools. However, many primary schools are beginning to use the *constituents* of a VLE separately in various ways. E-mail communication and online discussion can be restricted by problems with connectivity, but has substantial potential; the Internet is often used as a source of information and as more primary schools have effective connections to a broadband network more children can access quality online learning resources (Murphy 2003).

Use of a VLE is beneficial for communication, databases and the delivery of resources because the teacher can present, edit and shape the learning tools and resources to suit their purposes. Imagine a teacher takes her Year 4 class to the school resources centre, gives the children a topic to research, then asks them to talk together about what they have learned and produce a presentation as an outcome. Under these circumstances the learners are being offered the resources and given the task but it is difficult for the teacher to monitor and intervene in the learning at each step.

A VLE enables the teacher to have far more control of the task through the creation of 'learning units'. Teachers can select the web resources pupils will use and enable and monitor communication about what has been found out. When presentations are made they can be shared electronically. Thus a VLE can 'repackage' the learning experience to make it more focused and enable the teacher to monitor and intervene far more effectively than if the resources are used separately. The relevant potential uses of a VLE are shown in Tables 10.1, 10.2, 10.3 and 10.4 below.

Table 10.1 Effective usage of a VLE to facilitate communication (a) through e-mail, and (b) through a discussion board

(a)	
Aim	To e-mail.
What can VLEs do?	Provide secure e-mail facilities to communicate as individuals or groups.
Examples of effective use	E-mail can be used in a variety of ways to support learning. Not just for communication between learners and their teacher, but also to communicate more widely with the science communities, perhaps even globally (Murphy 2003)
(b)	
Aim	To use a discussion board.
What can VLEs do?	Provide a space for learners and/or teachers to discuss the topic at hand.
Examples of effective use	This has the advantage over a 'face-to-face' discussion in that it can be reread and added to, therefore deepening the level of reflection. A teacher might ask learners to use a particular set of resources as part of their project and learners might post messages to the discussions about the usefulness of the resources. In this way a range of learning styles and skills are supported by the use of the discussion board enabling the learners to develop a range of deeper and strategic learning styles (Gibbs 1999)

Table 10.2 Effective usage of a VLE to access databases and other resources (a) to access a library catalogue, and (b) to work with computer simulations

(a)	
Aim	To access a library catalogue, and other online resources.
What can VLEs do?	Provide direct access to the relevant part of online databases and resources, 'packaged' with tasks and selected by teachers, to meet groups' and individual needs, into 'learning objects'.
Examples of effective use	Online databases of such things as History resources can be used in research projects. Teachers can direct learners to the relevant parts of the database, rather than have them sort through layers. This saves time and reduces the possibility of learners going 'off task'. Increasingly this idea of construction of 'learning objects' is progressing and more complex packages of learning materials are being developed, including those which can be tailored to individual needs.
(b)	
Aim	Work with computer simulations.
What can VLEs do?	Provide access to teacher-created simulations.
Examples of effective use	Teachers and pupils can create simulations of events in video or animation software, which can allow learners to experiment with ideas and 'walk through' situations and work creatively. The National Endowment for Science, Technology and the Arts (NESTA) have funded a range of projects in the field of ICT and learning, including Sodaplay (NESTA 2005) which is designed to allow pupils in primary and secondary schools to create simulations as a design tool or to create science scenarios through modelling using virtual springs.

Table 10.3 Effective usage of a VLE in using presentation technology

Aim	Present findings and share outcomes with others.
What can VLEs do?	Provide file exchange and viewing systems for work to be transferred between teachers and learners.
Examples of effective use	VLEs provide tools for teachers and learners to communicate about work produced in flexible ways. Using e-learning portfolios, learners can construct their own areas to display written, pictorial and multimedia work. Teachers can access these when learners need support and comment on work in progress. This method of teaching, which is supported with formative assessment, is useful to support learners' individual needs. The Becta quality framework for e-learning resources (Becta 2005) endorses this approach.

Table 10.4 Effective usage of a VLE to facilitate assessment

Aim	To assess learners' understanding and knowledge.
What can VLEs do?	Provide teachers with tools to assess pupils learning through tests and quizzes, which can give immediate and formative feedback, or serve as end of unit assessments.
Examples of effective use	E-assessment is a rapidly growing field. Well-constructed e-assessment can support and augment effective practice (Becta 2005). There are some straightforward ways in which VLEs can be used to deliver tests made up of multiple choice, ordering or matching exercises. However there are also some challenges for e-assessment, where it might be developed to assess metacognition and thinking styles via simulated group work.

How can VLEs support effective learning in primary science?

The vast majority of teaching of science in UK schools is reported as being satisfactory or better (96 per cent at Key Stage 1 and 95 per cent at Key Stage 2 – OFSTED 2004), yet much of it is very tightly focused and doesn't allow for links to be made from one part of the science curriculum to another or to other subjects. According to OFSTED, effective teaching and learning in science is characterised by pupils being actively involved in thinking and carrying out scientific enquiry. Perhaps this priority might best be achieved as the creative potential and possibilities of practical cross-curricular working (inspired by the Primary Strategy in UK schools – DfES 2004) are explored. Flexibility in teaching approaches seems central here (OFSTED 2004).

Clearly, it is not just OFSTED that asserts that good teaching in primary science is closely built around the investigative process. The Association for Science Education's (ASE) journal *Primary Science Review* (PSR) reflects good practice associated with an active approach to learning in the primary classroom. A good example is presented in Robertson's review of the 'Let's Think' programme (Robertson 2004). Here, the theme of a practical approach to science closely allied to the investigative process is evident, with a focus on children's ability to hypothesise, discuss and draw conclusions about scientific ideas (Rowell 2004).

Accepting that practical investigative skills really should be at the centre of teaching and learning of primary science means teachers must try to give pupils opportunities to do the following, as set out in the National Curriculum (DfEE/QCA 1999):

- Ask and answer questions
- Observe and measure
- Recognise a fair test
- Follow instructions to control risks
- Explore
- Compare and consider
- Communicate

The crucial question is how the use of virtual learning might support this. To provide an answer we must first consider the prerequisite hardware required to access VLEs in the primary classroom. Having done so, we can examine ways in which VLEs might be used in the primary classroom to facilitate investigative learning.

Using hardware to access virtual learning

Interactive whiteboards (IWBs) have become an ICT 'essential' in a very short time. With funding dedicated to installing them in classrooms in every school in the UK through the Standards Fund (DfES 2003) and research showing that they can have benefits for both pupil motivation and teaching strategies (Becta 2003b), it may not be long before most teachers have access to this type of technology. In addition, with the increase in wireless technology, portable ICT devices such as laptops and – crucially for the primary school sector – tablet PCs are increasingly common. Used together, these devices allow primary aged pupils to see and interact with online resources in ways that were not previously possible. The ability to use 'touch screen technology', both in groups using an IWB and as individuals using a tablet PC, means that children need not wrestle with input devices such as mice or keyboards which are designed for adults. Small keyboards with fewer keys and pen technology mean that even when text is needed, there are fewer possibilities for mistakes to be made. In short, tablets, laptops and IWBs have made virtual learning more accessible.

In addition, increasing bandwidth has led to the development of web resources that are more suited to primary aged children because they utilise still and moving images to support learning. More imaginative website design that exploits words and icons also means that web-based resources are less reliant on text. Thus the multi-modal nature of the tools that might engage children's learning is strongly emphasised. These developments, coupled with the developments in hardware, mean that the technology is well suited to the introduction of more virtual learning in the primary classroom.

As with all technological developments, teachers will only really integrate them into their practice where real benefits for teaching and learning can be seen. The answer lies in the link between the underlying themes of this chapter: the uses of VLEs, the developments in hardware provision and good practice in science teaching pedagogy, based around the practical skills of scientific enquiry.

A VLE in primary science

The push to get broadband into UK schools has led the Regional Broadband Consortia to investigate what kind of teaching and learning tools can utilise the power of broadband, not simply by allowing schools to access the Internet quickly but also by making full use of the available bandwidth. Most of these consortia are now providing a VLE with a range of content, such as access to video and audio resources, as well as the opportunity to create individually tailored learning units and objects for pupils.

Like websites, VLEs have a homepage which children would see when they log on. This interface can be easily changed to reflect the users, using text or pictures to indicate links and adding or reducing the tools available to users as required. In addition to the notice board, pupils' files, a calendar, students' folios and text and image files known as 'learning objects' are shown in Figure 10.2.

Indeed, one of the most powerful tools of the VLE is the ability to create learning objects. In essence, this is a way to package up information, images and web links so pupils can access all they need from one page. This has advantages in that it saves time and keeps pupils on task. In its simplest form, the learning object would contain a question or task and a link or picture to use in answering the question (for example, Figure 10.3). Pupils can then either use paper or digital media to record their findings and post their responses to the teacher via the VLE.

E-mail is a powerful tool for communication and it is also one of the

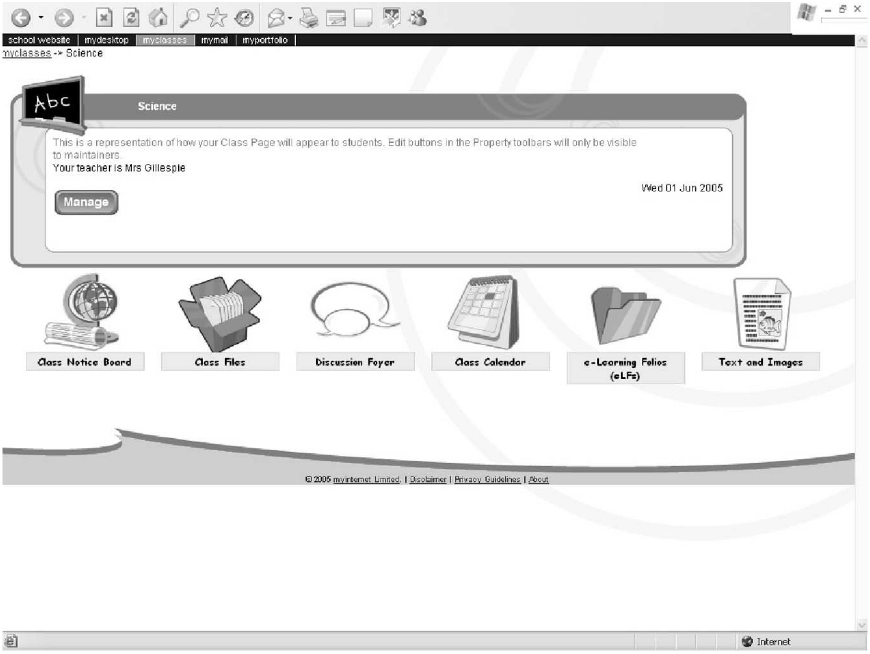


Figure 10.2 Example homepage for a VLE (created via the Netmedia Virtual Learning Environment).

simplest and most useful tools available via the VLE. This is a simple way for pupils and teachers to communicate with one another in a secure environment. A teacher might e-mail the class to remind them of homework or an assignment. Alternatively, imagine a teacher is working with a mixed Key Stage 2 class on a project about animals and finds a useful website. She e-mails this site as a link to all pupils (Figure 10.4), who are able to log on to the VLE at home. This supports their homework for the week, where they are collecting animal names and trying to classify them.

Let us consider some other simple examples of how a VLE could be further used to support primary science, with an emphasis on aspects of the science enquiry process. They do not represent complex or apparently 'advanced' use of ICT. In fact, using a VLE should make incorporation of ICT into primary science much more straightforward. However, they do show the range of opportunities that could be provided by a VLE.

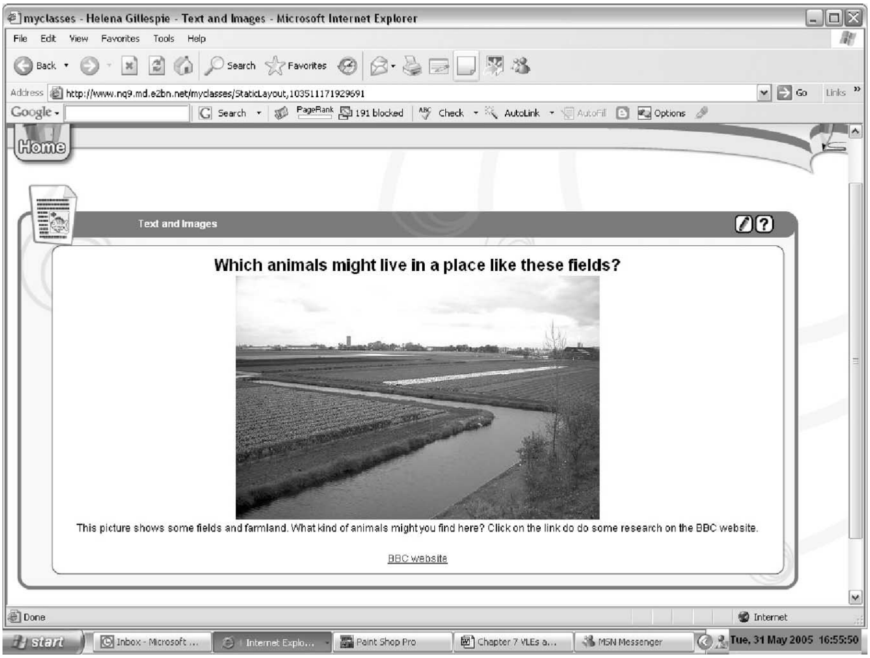


Figure 10.3 A simple learning object containing a question, a link and a picture (created via the Netmedia Virtual Learning Environment).

Ask and answer questions

Year 1 pupils follow a link in the VLE to the BBC website where they play on a science simulation game about forces. After a 20-minute session, working in pairs, their teacher asks them to work with their talking partners to come up with a question about what they have seen and learned on the site. They share these questions with the rest of the class and then decide on a question they can investigate as part of their practical science.

Observe and measure

Each week, children in Year 3 who are investigating the growth of plants over a period of time photograph a bean plant, a sunflower and some cress, all grown from seed. These photos are then put into three separate PowerPoint presentations and the children observe the changes which happen over the weeks by viewing the presentations via the VLE.

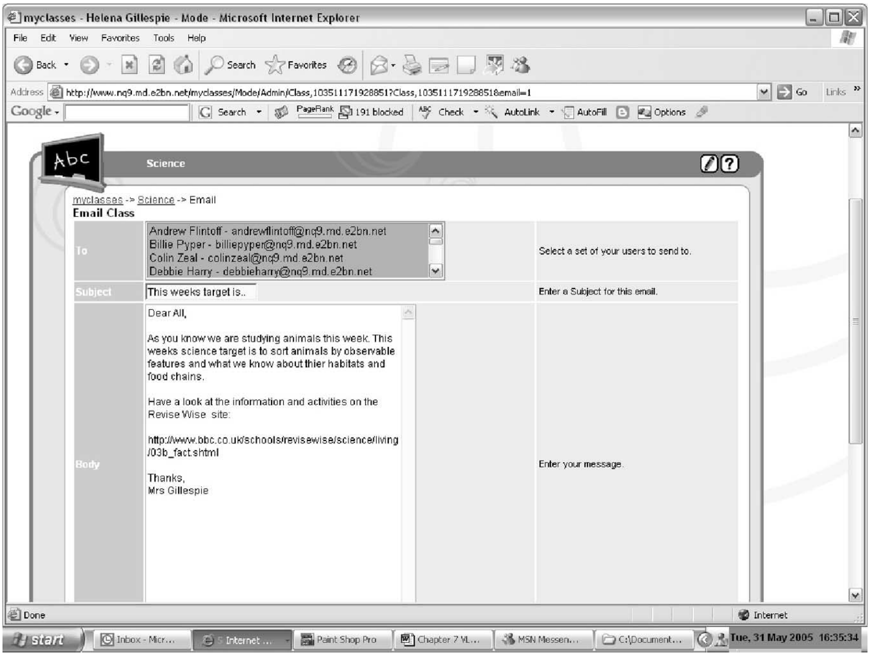


Figure 10.4 E-mail to pupils (created via the Netmedia Virtual Learning environment).

Recognise a fair test

Year 2 and Year 3 pupils are working on devising a fair test. The teacher constructs a simple investigation, rolling some cars down a ramp to see which car goes furthest. He videos the investigation three times, once as a fair test, once where he changes the height of the ramp and once where he varies the covering on the ramp as well as the car. The children view these videos via the VLE and are asked to say which is the fair test and why. After this activity the teacher introduces the children to the idea of simple variables and the children watch the videos again, this time naming the variables in each investigation and saying which have changed.

Follow instructions to control risks

Year 6 pupils are planning investigations into their topic on micro-organisms. Using links on the VLE they research practical investigations that could otherwise be harmful. They then share their findings on a discussion board and the teacher uses excerpts from this discussion to construct a list of 'dos' and don'ts' for the topic.

Explore

Year 4 pupils in an urban school could investigate their school habitat. They use a link on the VLE which takes them directly to the BBC's 'birdcam' where they can compare the birds they see in their school with the countryside-based birdcam. They keep records of what they see via the VLE's discussion board, which logs dates and times birds are spotted as messages are posted.

Compare and consider

Groups of Year 5 pupils construct a simple, one-page PowerPoint presentation about what they have found out about the effects of the sun and moon on the Earth. They use links to the Science Museum website via the VLE as a starting point for their research. Their finished slides are linked together into a presentation by the teacher, who then posts this to the VLE. In a subsequent lesson, the pupils are asked to summarise in pairs what groups have found out.

Communicate

A teacher of a Year 4 class is working on a project about habitats around the world. Linking up with teachers in different countries, the class exchange e-mails and information about plants and animals in their local area.

Conclusions

Good use of information and communications technology in teaching does not have to use complex hardware or applications. Virtual learning environments *can* make using technology in primary science teaching simpler, by collecting together resources to support research, by enabling pupils to interact with resources such as moving images and by encouraging communication and collaboration. But the question is *will* they and, if so, *when*?

The answers are not straightforward. Barriers to successful integration of virtual learning still exist in areas like the professional development of teachers, availability of suitable hardware and even in the curriculum and assessment systems currently in place. However, if these barriers can be overcome the possibilities for virtual learning in primary science are diverse and numerous and could help to support the best practical science teaching, which focuses on the investigative process and on children engaging in real science learning.

References

Becta (2003a) *A Review of the Research Literature on the Use of Managed Learning Environments and Virtual Learning Environments in Education, and a Consideration of the Implications for Schools in the United Kingdom*. Coventry: Becta.

Becta (2003b) *What the Research Says about Interactive Whiteboards*. Coventry: Becta.

Becta (2005) *BECTA's View. A Quality Framework for E-learning Resources*. Coventry: Becta.

Department for Education and Employment (DfEE)/Qualifications and Curriculum Authority (QCA) (1999) *Science – The National Curriculum for England: Key Stages 1–4*. Norwich: HMSO.

Department for Education and Skills (DfES) (2003) *Fulfilling the Potential*. London: DfES.

DfES (2004) *The National Primary Strategy. Transforming Teaching and Learning through ICT in Schools*. London: DfES.

Gibbs, G.R. (1999) 'Learning how to learn using a virtual learning environment for philosophy', *Journal of Computer Assisted Learning*, 15: 221–231.

Harrison, C., Comber, C., Fisher, T. *et al.* (2002) *ImpaCT2: The Impact of Information and Communication on Pupil Learning and Attainment. Strand 1 Report*. London: DfES.

JISC (2002) *Managed Learning Environment Activity in Further and Higher Education in the UK*. London: JISC.

JISC (2005) 'Virtual and managed learning environments', http://www.jisc.ac.uk/index.cfm?name=issue_vle_mle (June 2005).

Laurillard, D. (2002) *Rethinking University Teaching: A Framework for the Effective Use of Learning Technologies*. London: Routledge Falmer.

Murphy, C. (2003) *Literature Review in Primary Science and ICT*. Bristol: NESTA Futurelab.

National Endowment for Science, Technology and the Arts (NESTA) (2005) 'News releases', http://www.nesta.org.uk/mediaroom/newsreleases/3863/index.html (June 2005).

Office for Standards in Education (OFSTED) (2004) *OFSTED Subject Reports 2002/03: Science in Primary Schools*. London: HMSO.

Pittinsky, M. (2002) *The Wired Tower: Perspectives on the Impact of the Internet on Higher Education*. Upper Saddle River, NJ: Financial Times/Prentice Hall.

Robertson, A. (2004) 'Let's Think! Two years on', *Primary Science Review*, 82: 4–7.

Rowell, P.M. (2004) 'Why do bees sting? Reflecting on talk in science lessons', *Primary Science Review*, 82: 15–17.

Salmon, G. (2004) *E-moderating: The Key to Teaching and Learning Online (Second Edition)*. London: Kogan Page.

11

ICT AND PRIMARY SCIENCE – WHERE ARE WE GOING?

Angela McFarlane

From the richness and complexity of human endeavour three domains of knowledge have been selected and privileged above all others to form the core of the UK education system. The study of language, mathematics and science are legally compulsory for all students from the ages of 5 to 16 and attainment in these subjects is the sole measurement by which the success or failure of our primary education system is judged. For this reason, it is worth considering why it is science rather than, say, humanities, creative arts, philosophy or any other field that has been chosen for such special investment, what we as a society hope to achieve through this focus and the extent to which we are indeed doing so.

Castells (1996) in his definitive trilogy *The Information Age: Economy, Society and Culture* sets out his analysis of the rise and implications of 'the network society'. In the early twenty-first century it seems we inhabit a world where economic prosperity and all that depends on this – democracy, health, our very survival and that of the species with which we share our planet and on which we in turn depend – rests on the ability to benefit from the effects of globalisation. According to the 'Globalisation Guide' website (www.globalisationguide.org), 'Globalisation is the rapid increase in cross-border economic, social, technological exchange under conditions of capitalism'. Globalisation is both fuelled by and fuels the unparalleled ability we now have to share information across boundaries of time and geography as a result of the web of communications technologies we share. There is a network of social and economic interdependencies which criss-cross our world and depend on communications technologies and a level of connectivity that is unprecedented in human history. The technologies we use to support this web of communication are the result of over a hundred years of development that started, according to the Smithsonian Institute, with Morse's invention of the telegraph in 1837. His was the first machine to transmit information over long distances almost instantaneously. Today this simple notion has developed into the enabler of the so-called 'knowledge economies' where wealth creation depends on an ability to innovate. As a result our technology and information-rich era is also known as the 'knowledge age', where knowledge creation is or is predicted to be the basis of wealth and economic growth in developed nations for the first half of the twenty-first century. As a consequence of this vision there are widespread calls for our education systems to change in order to prepare learners to take their place in a knowledge economy.

It seems that to take a place in this connected world we have decided young people need to be able to use language, work with number and shape, and know about science (OECD 2001). It is interesting to note that the curriculum requires only one language in the case of England – the other global languages including Spanish and Chinese, which are used by as many people as English, being almost entirely ignored in primary education in the UK. It may be that the Anglophone dominance of communications technologies has reinforced this linguistic isolationism, although change is on the horizon as we wake up to the need to work in languages other than English. Currently, however, we are not only limiting the scope of languages our young people experience, we are also taking a very partial view of the necessary competences they need in English. It is the use of the written form of language that has dominated schooling, with other forms of communication such as film or multimedia almost ignored and even speaking and listening skills being seemingly relegated to a poor second place despite their central importance in everyday life. Nowhere is this more evident than in the explosion in the use of voice-dependent technologies such as telephony. Consider how many everyday business exchanges that used to be undertaken in writing are now dealt with entirely by telephone – albeit often through interaction with a semi-automated system. Indeed, the use of voice-based technology is set to undergo a further expansion with the use of voiceover Internet protocols (VIP) making voice communication worldwide cheap and accessible to a much wider user base. Even as I am writing this chapter the Internet search engine company Google has announced their venture into the Internet voice communications arena.

This, then, is something of the background of worldwide development against which structures and developments within the education system might be held to account. Against this background, the following remarks consider the place of science education and, in particular, some of the issues associated with an examination of some of the more anachronistic features of the UK school science curriculum.

The role of science in the curriculum

It seems that science is seen as a necessary preparatory experience for life in a technologically framed world, where innovation and knowledge creation are seen as key to economic success for the individual and the nation. So what is it about science that could have led policy makers to this conclusion?

If the study of science is meant to underpin a technology dependent culture, why is science and not technology itself the core subject? Is it because the 'pure' sciences underpin subjects such as engineering and computer science, biomedical sciences and material science? Will knowledge of the sciences aid an understanding of these more applied fields? The domains of science chosen for the school curriculum, especially that of the primary key stages, do not obviously suggest this. Indeed, it is difficult to infer the logic behind the selection of content in the school science curriculum beyond a clear desire to represent the three traditional school subjects of biology, physics and chemistry. These selections may reflect the personal histories and allegiances of those who wrote the curriculum since they do not necessarily map onto any significant practice of science beyond school. After that an air of stamp collecting invades the UK science curricula, with a smattering of pretty examples from a range of countries in the album. Clear linking themes, or big ideas, or even progression of understanding across the elements or the key stages are, however, sometimes hard to discern.

The identified skill sets behind the curriculum show a welcome coherence in contrast, since they are present in all four key stages. These skills are set out in detail in Chapter 2 and I will not repeat them here. The key skills are predicated on an experimental model of science, where hypotheses are tested through investigation and observation and conclusions drawn based on the evidence accumulated. However, this model of science, and the so-called scientific method, is only one approach to the development of scientific understanding. The use of models in science, as discussed in Chapter 6, is just one alternative. It is not clear why we devote 11 years of schooling to one experimental method, or why even then we do not apparently teach this very well, hypothesising being particularly poorly developed (see the House of Lords 2001 and House of Commons 2002 reports on this topic). As pointed out in Chapter 3, the competencies credited in tests of science learning used in England can equally well be acquired through drill and practice as through an experimental approach. Moreover, there is very good evidence that if it is understanding of scientific content that is the objective, the experimental approach leaves much to be desired (see McFarlane and Sakellariou 2002 for a discussion of this).

A skill set vital to science that is not even mentioned within the defined curriculum is the ability to recognise and take part in reasoned, evidence-based discussion. This may be because this skill set is not unique to science, but is central to an active intellectual life in any knowledge domain in western society. However, there is little evidence of reasoned discussion elsewhere in the curriculum, even as a desired cross-curricular aspiration in the introductory parts of the curriculum orders (which encapsulate many worthy aims but rarely seem to influence practice in teaching or assessment). Fortunately, despite this absence in the curriculum orders, debate and argumentation have been the subject of a small number of highly important research and development projects and are certainly achieving prominence in post–16 science courses, particularly those dealing with bioethics, such as the Salters-Nuffield A-level biology course.

The ability to recognise and distinguish between ideas and beliefs is at the heart of this process and in an ever more complex world is a vital skill set for everyone who ever has to make a choice about the use of technology – either for themselves, a dependant or society at large. We are faced daily with questions about our own behaviours that affect others directly through the process of globalisation – from which brand of coffee to buy, to vaccinating our children, to who we should vote for if we care about climate change policy. All of these issues have at their heart a need to understand and respond to a range of views, arguments and counter-arguments in order to make an informed personal choice. We also need to be able to recognise when we and others make decisions from the head or the heart, using ideas or beliefs, evidence or instinct. This is not about making the right choice, it is about making informed choice; not about being told what to think or do, but to understand how and why we think and act and to take responsibility for the consequences. And all the while to recognise that there will always be a degree of uncertainty, and that there is almost never an entirely risk-free answer.

It will be clear from the above that there is much debate concerning the nature and purpose of school science (see House of Lords 2000). If we consider purpose, is the main purpose of school science to winnow out what will inevitably be a minority for a science-related career, or to prepare all for active participation in a scientifically based culture? Arguably, at the moment the school science curriculum in the UK does neither well and in fact needs to do both, with scientific literacy a requisite for all. We have only to look at the level of science discourse in the popular media to realise that whatever else science education has achieved in the last 100 years, general scientific literacy is not among the accolades we can boast. We have, however, been good in the past at educating science specialists. The

UK leads the world in a range of scientific and technology enterprises as a result, and we must not forget this in the gloom that tends to attach to policy debates around science education. However, even here there is no room for complacency; we have lost ground as undergraduate recruitment stagnates and the numbers taking any science post-16 are not growing.[1]

As I have suggested, it is easy to find evidence of our poor scientific literacy in the popular media, where even on otherwise intellectually robust platforms we daily hear such remarks as 'we need to be able to buy our vitamins free of chemicals' (as in a piece on threatened EU legislation on dietary supplements on the *Today* programme on BBC Radio 4). A recent exchange in a weekend broadsheet was more thought provoking. A short and admittedly light-hearted piece advised readers not to look up information on their health worries on the Internet on a Friday as the result would be a certainty that they did indeed have a terminal complaint. The weekend would then be ruined as they waited and worried until Monday to get the reassurance they needed from a doctor that this was not in fact the case. The following week saw a response from a reader who had secured the treatment she needed for her daughter and avoided the loss of sight in one of her eyes with the aid of information and support she had accessed through the Internet. A rare condition – unlikely to be seen by an individual GP – was diagnosed, a worldwide community of sufferers and their parents joined and consulted, and a child's life changed immeasurably through the use of communications technology.

Surely an objective of good scientific education in the information age should be to equip learners with the skill sets they need to deal with either of the situations described? Indeed, patients turning up with printouts from the Internet is now commonplace for primary healthcare professionals and the 'expert patient' initiative is a web-based project backed by the National Health Service to encourage patients with chronic conditions such as diabetes and arthritis to share information and experience in order to make living with their condition as easy as possible.

ICT and scientific reasoning

The sheer amount of information now available to any individual is enormous and pupils need to be equipped to evaluate it and build personal knowledge. They need to know how to distinguish a statement which may be true (e.g. our sun is 4.5 billion years old) from a fact (e.g. the earth moves around the sun) and how to distinguish the knowledge produced by pseudo-science (e.g. astrology) from science (e.g. astronomy). Moreover, modern society requires citizens to make decisions on many issues related to the cultural implications of scientific achievements (e.g. cloning). For these reasons public understanding of science necessitates that pupils understand not only the content of science, but also its methods. It is argued (Driver *et al.* 1996) that emphasising scientific knowledge is not enough for pupils to be scientifically literate. They need to be introduced to the ways that scientists came to these conclusions.

But the way that scientists come to conclusions is not entirely straightforward or uniform. Helms (1998: 128) identifies scientific method as all the skills and processes, technologies and tools employed by scientists to gather valid and reliable data in order to verify, falsify or formulate a theory. This is very similar to the model that the UK National Curriculum identifies above others. Other authors (Hodson 1985; Driver *et al.* 1996; Leach 1998) argue that epistemology shows that there is not a single method or an 'algorithm' (Millar 1996: 15) that scientists follow in order to solve a scientific problem. Some scientists perform experiments whereas others do not. For instance, astronomers cannot intervene to conduct an experiment since they are only able to see what happened in the past (sometimes millions of years ago) in systems they cannot possibly influence. In addition, while some scientists develop a theory after experimentation, sometimes theories come first and experimentation supports or disproves the theory later.

The above examples illustrate the diversity of strategies that real scientists employ and also that scientific method cannot be templated. Therefore, if there is not any simple algorithm which describes sufficiently the ways that scientists work, can the scientific method be taught? It is difficult, if not impossible, for pupils to learn all scientific strategies through school investigations. Nevertheless, it might be realistic to introduce pupils to at least some of them. Here I want to concentrate on the understanding of the relationship between *evidence*, the *conclusions* based on that evidence and the development of rational-calculative approaches to this relationship which can be termed 'scientific reasoning'. A very simple proposition can usefully illustrate the underlying objective of a science curriculum aimed at developing scientific reasoning. A student who has successfully completed such a curriculum, when faced with the report of a scientific investigation in the popular media, would automatically ask the questions 'How do they know that?', 'Who is writing this?', and perhaps 'Who is paying for this work?'. Whilst the non-expert cannot be expected to interpret the raw data, or even perhaps the arguments put in full in the original source, the scientifically literate will have the requisite skills to interpret the more popular reports and make a valid judgement as to the likely validity or otherwise of their claims, as well as any likely bias in interpretation based on its provenance and the credibility of its sources. In particular, it should be possible to question whether the logical deductions in the argument are sound and if the data offered does indeed support the conclusions drawn. This will involve the understanding of and ability to apply such concepts as probability, risk and certainty[2] which allow us to make judgements as to the likely validity of such reports, and the personal and social consequences associated with related behaviours or policy decisions. These skills have always been important to an individual who wishes to play an active role in any democracy with a culture underpinned by science and technology. Arguably, in this era of information overload they are essential. How else are we to avoid intellectual paralysis as we are bombarded with information and mis-information, claim and counter-claim on such important topics as food safety, genetic manipulation, nuclear power, climate change and environmental pollution? Anyone who takes any interest in these issues can easily discover an overwhelming range of sources of conflicting information through print and electronic media, some original research reports as well as critiques and analyses based on them which may be interpreted from very particular positive or negative perspectives.

Home access to the Internet is growing and access through libraries and other public facilities such as learning centres mean anyone who wants access to the World Wide Web in the developed world can have it pretty much irrespective of income or age. The skills needed to turn this overwhelming sea of information into authentic knowledge include an ability to search vast multimedia sources, identify and interpret relevant information, critique sources in terms of provenance including source, accuracy, validity and reliability, weigh evidence which may be conflicting, and finally collect and synthesise sources into an authentic representation of personal knowledge. These are important elements of ICT literacy which are relevant to scientific literacy and to the development of scientific reasoning.

Extensive discussion of scientific literacy and the relevance of such literacy to science education has, of course, taken place elsewhere (see Osborne 2002). Here I wish only to flag the importance of the role of the Internet and the World Wide Web as contexts for the development of these important skills sets. This is particularly so when the experience of access to information sources, including broadcast and Internet media in the wider community, is growing so rapidly and is such a central part of young people's experience of the world beyond school (Buckingham and McFarlane 2001).

Electronic communications

Much prominence is given to the facility that electronic communications affords educational users to access vast quantities of information from an ever-expanding range of sources. Indeed, scientific sources are at the forefront of this trend as the speed of discovery and dissemination of findings outstrips the rate at which print sources can support the culture of scientific research. It is well known that the original protocols for communicating information over what has become the Internet were devised to support sharing of data between physicists working at laboratories in Switzerland, Italy and England (CERN 2001).

Unfortunately, education policy in the UK has tended to focus on the ability of these networks to disseminate information rather than to support communication. Whilst brief mention is given to student involvement in production and publication, the model implicit in the 'Curriculum on-line' consultation paper produced by the Department for Education and Employment (now Education and Skills) is firmly one of broadcast of digital content to a receptive audience (DfEE 2001). Much of the discourse still tends to assume a view of education – including science – as a process of passing on a discrete body of knowledge to the learner. This is to miss an opportunity to use the developing ICT infrastructure as a means of developing students' ability to be critically informed users and producers of information and, in the case of science, to develop the skills needed to apply scientific reasoning skills to the analysis and critique of related information sources. There is an important role for the active learner here in the manipulation and production of multimedia sources (Bonnett *et al.* 1999). Thus the model of science education which fully exploits electronic media should incorporate both the location and analysis of scientific information and the publishing of the resulting critique as part of an active electronic community of learners. In this way school pupils can expose their interpretations of science to peer review and truly experience the way research proceeds in an authentic fashion.

Reasoned argument in the primary classroom

So if this degree of scientific reasoning is a key objective of science education, how might the foundations be prepared in the primary curriculum? Work with philosophy in the primary curriculum shows that even young children are capable of engaging with debate and reasoning (Lipman 1988). We know that Key Stage 2 children use the Internet regularly and have a worrying degree of confidence in what they find there (McFarlane and Roche 2003). We also know that children are very aware of politicised scientific issues such as conservation and climate change and that they can be left feeling disturbed and disempowered as a result (Chapter 2 in this volume). The context for work on authentic consideration of scientific issues is set and indeed there is a real need to support children's engagement with issues that they find troubling.

To map how such issues might be tackled in the classroom it is useful to point to much relevant and important work in this area that is already ongoing. Of particular concern is how pupils might be brought to a critical awareness of (and engagement with) the nature and methods of science (Warwick and Stephenson 2002). Put another way, the challenge is to 'design instructional sequences and learning environment conditions that help pupils become members of epistemic communities' (Duschl 2000: 188). This is the primary concern of the ongoing EPSE project (see Chapter 1 in this volume), whilst the ASE and King's College Science Investigations in Schools project (AKSIS – Goldsworthy *et al.* 2000: 4) has 'explored the effects of Sc1 in the National Curriculum on current practice and made recommendations for its future development'. AKSIS has had, as a central concern, the exemplification of different types of scientific enquiry and the production of materials to support pupil thinking in relation to the processes of scientific enquiry. A substantive part of this work has been predicated on the notion that if procedural understanding and a wider understanding of the nature of science are to be developed, a vital element of the process is necessarily the extent to which evidence is questioned. It could be argued that the interpretation of evidence is the activity around which all the understandings in science, and of science, pivot. With reference to science education, Duschl (2000: 189) cites Driver *et al.* (1996) in stating that the evaluation of evidence is one of three strands of curriculum emphasis that 'explicitly establish an epistemological basis for scientific knowledge claims'. Thus, research into the uses and interpretations of all forms of evidence is central to elucidating pupils' developing understandings of the personal relevance of science. Warwick and Siraj-Blatchford (in press) recognise that 'the development of a science education that includes a focus upon the nature of science suggests the need for "pedagogic tools" that can be used to engage children with the procedural understandings that are central to a scientific approach to enquiry'. Amongst these tools they report that the use of secondary data for comparative analysis of secondary and investigative data can provide a basis for such engagement. However, they note that 'such comparative analysis will only mirror the collaborative nature of the scientific enterprise where children have guided opportunities to discuss their understanding of the issues revealed by the comparisons . . . (and where) . . . the data is contextualised through connection with the knowledge claims made in science'.

But it seems that in some cases the curriculum is still a long way from even recognising the importance of teaching such critical engagement, whilst the uses of information technologies do not seem to be strongly allied to this purpose. In recent work with post-16 teachers it was surprising to find frustration with students' rather unthinking use of electronic sources, with claims that students tend to use cut and paste uncritically rather than engage with the sources. Yet even though these same teachers and students had been in the same schools for some six years, there was no recognition that this inability to make meaningful use of electronic sources might highlight a deficit in the study skills developed while in the school. Science teachers, it seems, are commonly ill-equipped to teach science in a way that prepares students for citizenship and decision-making (Levinson and Turner 2001; House of Commons 2002). Children, however, do want to know about contemporary science and to engage meaningfully with investigations (Osborne and Collins 2002).

Given the level of use of the Internet even in Key Stage 2 we cannot wait until secondary school to begin to teach children how to make meaningful, critical use of information sources. By the age of 12 bad habits may already be well established. Rather, we need to develop good questioning skills from the earliest stages, and where better to begin with the development of these skills than in science? Science, after all, is all about asking questions and the best scientists ask the best questions. Yet all too often the questions we explore in science are not particularly good or inspiring, and they are certainly not the questions the children would ask. In many lessons we set up contexts that are full of pitfalls for anyone who diverges from the set path as the science around them is complex and hard if not impossible to demonstrate in the classroom. Whoever decided the physics of running cars down a ramp was easy?

However, by talking about systems we are examining and facing up to what we can and cannot deduce about them; we can learn as much, if not more, about both the system and the processes of scientific reasoning as we can through manipulating apparatus in search of an answer. In science, knowing what we cannot know is as important as knowing what we can know. Pretending that science has all the answers is perhaps the greatest disservice we can do, to pupils and to science. And all too easily this can be the impression gained by young investigators, who have to leave an 'experiment' with an answer. In fact, all too often their observations are not adequate to get to an answer. For example, you may have seen that large sugar crystals take longer to dissolve than small ones, but can you be sure why this is just by observing them? One memorable training video showed a group left firmly convinced this is because the large crystals had an invisible coating on them. This conclusion had their teacher stumped and with no time to challenge this view as the class had to move on to another topic. Yet it is perhaps one of the commonest failings of the trainee experimental scientist, and social scientist, to extrapolate their conclusions beyond anything the data can support.

Conclusion

To speak of the role of ICT in science education it is necessary first to identify the objectives of that education and then disaggregate the various forms of ICT in order to discuss the potential relevance or otherwise of each. Where investigative science plays a central part, there are applications of ICT which can both support 'live' investigation and some which can replace it, providing a virtual system to investigate using the same principles as in the laboratory. Moreover, models of the idealised system can be animated alongside a simulation of the real system to reinforce the relationship between practice and theory.

A second and complementary method can be to adopt an analytical approach to scientific information found in popular and scientific literature, especially the wealth of each available on the Internet. Where an understanding of various scientific methods and the relationship between evidence and conclusions are required this can be a more potent experience, dealing as it does with science that cannot be replicated in school and topical subjects of greater inherent interest to pupils than much of the rather stodgy content still found in the school curriculum.

In following either of these approaches exclusively there may be a danger of creating a social divide in school science, where perhaps the more able follow an empirical science curriculum and the less able the more populist model. In order to avoid such a potentially divisive curriculum, it might be better to model a curriculum for all which has an equitable balance between investigative empirical science, supported with ICT so that it is more effective, and investigative critical science which is supported through access to scientific sources and published analysis shared and discussed with peers. In this way pupils will experience a range of approaches to science which will be more likely to enthuse them to follow a career in science, and ensure they become scientifically literate citizens. This process cannot begin too early.[3]

Notes

1 A recent report by the higher education funding council into the state of vulnerable subjects at university level concluded that the closure of university physics departments per se was not a cause for concern since the number of students studying the more contemporary but related branches of physical science was compensating for the decline. Time will tell if this interpretation of the situation prevails.

2 Probability and risk remain poorly understood concepts as illustrated by a personal favourite, when media reports put the odds of winning the lottery at less than those of contracting new variant CJD (Creutzfeldt–Jakob disease). Meanwhile government sources were encouraging the population in the one hand to buy lottery tickets and on the other to continue to eat beef.

3 Some parts of this text appeared in an earlier paper written with Silvestra Sakellariou and published in 2002.

References

Bonnett, M.R., McFarlane, A.E. and Williams, J. (1999) 'ICT in subject teaching – an opportunity for curriculum renewal?' *The Curriculum Journal*, 10 (3): 345–359.

Buckingham, D. and McFarlane, A.E. (2001) *A Digitally Driven Curriculum?* London: Institute for Public Policy Research.

Castells, M. (1996) *The Information Age: Economy, Society and Culture – Volume 1: The Rise of the Network Society*. Oxford: Blackwell.

CERN (European Organisation for Nuclear Research) (2001), http://public.web.cern.ch/Public/ACHIEVEMENTS/web.html

Department for Education and Employment (OfEE) (2001) 'Curriculum on-line – a consultation paper'. London: DfEE.

Driver, R., Leach, J., Millar, R. and Scott, P. (1996) *Young People's Images of Science*. Buckingham: Open University Press.

Duschl, R. (2000) 'Making the nature of science explicit', in Millar, R., Leach, J. and Osborne, J. (eds) *Improving Science Education: The Contribution of Research*. Buckingham: Open University Press.

Goldsworthy, A., Watson, R. and Wood-Robinson, V. (2000) *AKSIS Investigations: Developing Understanding*. Hatfield/Cambridge: ASE/Black Bear.

Helms, J.V. (1998) 'Learning about the dimensions of science through authentic tasks', in Wellington, J. (ed.) *Practical Work in School Science – Which Way Now?* London: Routledge.

Hodson, D. (1985) 'Philosophy of science, science and science education', *Studies in Science Education*, 12: 25–57.

House of Commons Science and Technology Committee (2002) *Science Education from 14 to 19*. London: The House of Commons Stationery Office, http://www.rsc.org/pdf/education/scied1419.pdf

House of Lords (2000) *Science and Society: 'The Jenkin Report'*. Select Committee on Science and Technology, Third Report, 23 February 2000 by the Select Committee appointed to consider Science and Technology.

House of Lords (2001) *Select Committee on Science and Technology First Report*. London: United Kingdom Parliament, http://www.parliament.the-stationery-office.co.uk/pa/ld200001/ldselect/ldsctech/49/4901.htm

Leach, J. (1998) 'Teaching about the world of science in the laboratory: the influence of students' ideas', in Wellington, J. (ed.) *Practical Work in School Science – Which Way Now?* London: Routledge.

Lipman, M. (1988) *Philosophy Goes to School*. Philadelphia: Temple University Press.

McFarlane, A. and Sakellariou, S. (2002) 'The role of ICT in science education', *Cambridge Journal of Education*, 32 (2): 219–232.

McFarlane, A. and Roche, E. (2003) 'Kids and the net: constructing a view of the world', *Education, Communications and Information*, 3 (1).

Millar, R. (1996) 'Towards a science curriculum for public understanding', *School Science Review*, 77 (280): 7–18.

Organisation for Economic Co-operation and Development (OECD) (2001) *Schooling for Tomorrow Series – Learning to Change: ICT in Schools*. Paris: Organisation for Economic Co-operation and Development.

Osborne, J. (2002) 'Science without literacy: a ship without a sail?', *Cambridge Journal of Education*, 32 (2): 203–218.

Warwick, P. and Stephenson, P. (2002) 'Reconstructing science in education: insights and strategies for making it more meaningful', *Cambridge Journal of Education*, 32 (2): 143–151.

Warwick, P. and Siraj-Blatchford, J. (in press) 'Using data comparison and interpretation to develop procedural understandings in the primary classroom: case study evidence from action research', *International Journal of Science Education*.

INDEX

OPEN UNIVERSITY PRESS
McGraw - Hill Education

TEACHING AND LEARNING PRIMARY SCIENCE WITH ICT

This book provides a range of insights into pupils' learning relevant to the use of information and communications technology (ICT) in primary science. The contributors, who are all experts in their field, draw on practical and theoretical perspectives and:

- Provide specific examples of software and hardware use in the classroom
- Consider innovative and creative uses of technology for pupils engaged in science activity in the primary and early years
- Indicate future possibilities for the use of computer-based technologies

Key themes running through the book include: setting the use of ICT in primary science within theoretical perspectives on learning and on pedagogy; the importance of using ICT in developing talking and listening opportunities in the science classroom; and the potential of learning through ICT enhanced science investigations. Contemporary issues such as inclusion, creativity and collaborative learning are also examined, making *Teaching and Learning Primary Science with ICT* essential reading for students in science education, and for teachers who want to use new technology to improve learning in their science classrooms.

Paul Warwick is a lecturer at the Faculty of Education, University of Cambridge. Previously he was a primary school deputy head teacher and an adviser for science for a local education authority.

Elaine Wilson is a lecturer at the Faculty of Education, University of Cambridge. She has taught secondary science in a range of schools.

Mark Winterbottom is a lecturer at the Faculty of Education, University of Cambridge. He taught science in upper schools in England for five years.

ISBN 0-335-21894-6

9 780335 218943

www.openup.co.uk