

REPORT 5:

Literature Review in Primary Science and ICT

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FOREWORD

This review focuses on the development of primary science since it was first introduced in 1989 as a compulsory, core subject in the primary curriculum in England and Wales. It considers the impact of ICT in primary science in relation to the role of teacher and learner, teachers' subject knowledge, the balance between process skills and science content, and the application of formative assessment. It also provides a critical evaluation of ways in which ICT is currently being used to promote good science teaching.

While the importance of informal learning is recognised, this review focuses on the development of science learning particularly in primary schools.

It should be noted that Futurelab's partner publication 'Science Education and the Role of ICT' (2003) provides a guide to the history, principles, debates and practices of science teaching in the 21st century and explores the development of science in secondary schools. A further Futurelab report, to be published in early 2004, will address the key role of informal learning in science education.

We are keen to receive feedback on the Futurelab reports and welcome comments at research@futurelab.org.uk.

Martin Owen
Director of Learning
Futurelab

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EXECUTIVE SUMMARY



EXECUTIVE SUMMARY

This review focuses on the development of primary science since it was first introduced in 1989 as a compulsory, core subject in the primary curriculum in England and Wales.

In a review of the first ten years of compulsory primary science, Harlen (1998) identified current concerns as: the teacher's role in constructivist learning, teachers' subject knowledge, the balance between process skills and science content, and the need for greater understanding and application of formative assessment. Harlen also anticipated that the foremost foreseeable change in the learning and teaching of primary science over the next ten years would be the impact of information and communications technology (ICT).

This review will consider the impact of ICT in primary science in relation to the areas identified by Harlen (1998) and provide a critical evaluation of ways in which ICT is currently being used to promote good science teaching. It will reflect on the science and ICT 5 year-old children of today need to learn in order to enable them to become scientifically and computer-literate by the time they are 20. It will argue, after Yapp (2003), that primary education should provide children with more languages, scientific and technological awareness and confidence, cultural sensitivity and media awareness. The skills these children develop should include team working, creativity, innovation and learning how to learn.

Informal learning should be valued as much as formal learning (Yapp 2003).

SCIENCE IN THE PRIMARY SCHOOL

Primary science is concerned with three broad areas: energy and forces; materials; and living things, which lay the foundations for physics, chemistry and biology respectively. Whilst these are the broad areas of study, primary science is not just concerned with knowledge, but more particularly with the scientific method and the effect of the use of this method on the individual child¹. It is **child active**, developing both manipulative and mental activity. It is **child focused**, concentrating on an aspect of the world the child experiences and in which the child can display an interest.

Primary science has three aims: to develop scientific process skills, to foster the acquisition of concepts and to develop particular attitudes.

Science is currently one of the three core subjects in the primary curriculum and, together with English and mathematics, is formally assessed at the end of primary schooling in England and Wales, and it is part of the Transfer Procedure Test, which is taken in the final year of primary school by those pupils who wish to attend grammar schools in Northern Ireland.

¹ See the partner Futurelab publication 'Science Education and the Role of ICT: Promise, Problems and Future Directions' Osborne and Hennessey (2003) for a full discussion of the debates surrounding the role of science education in UK schools, in particular the relative emphasis on scientific 'content' versus scientific 'thinking'.

RESEARCH INTO CHILDREN'S LEARNING IN SCIENCE

Research on children's learning in science over the past 30 years has been influential in primary science teaching in the UK, particularly since the introduction of compulsory science for all children between the ages of 5 and 16.

The National Curriculum for England and Wales, 5-14 National Guidelines in Scotland and the Northern Ireland Curriculum were all introduced in the late 1980s and early 1990s. These defined for the first time what aspects of science should be taught at primary level. Decisions regarding the content and pedagogy of primary science were made using evidence from major research projects. The Assessment of Performance Unit (APU) surveyed children's science knowledge at the ages of 11, 13 and 15 during the 1970s and 1980s, and outlined what these children should be expected to do in science.

Two other projects were influential. The SPACE (Science Processes and Concepts Exploration) project (1990-98) investigated children's scientific ideas and the STAR (Science Teaching Action Research) project studied classroom practice in relation to process skills. Harlen (p25 in Sherrington, 1998) has discussed the impact of these projects. In summary, they - together with other international projects - generated major interest in children's own scientific ideas, which has given weight to constructivist approaches towards learning in science.

Constructivism has its roots in psychology, philosophy, sociology and education. Its central idea is that human learning is

'constructed' - learners build on the foundations of previous knowledge. Learning is therefore an active, rather than a passive process. Constructivism has major implications for science teaching; it calls into question the traditional, 'utilitarian' practices and places the child at the centre of the learning process. The popularity of constructivist approaches to science teaching has been steadily increasing over the past 30 years.

Many criticisms have been levelled against the constructivist approach to science teaching in the primary school. The most frequently quoted of these is that, whilst the research advises that teachers identify children's alternative frameworks and already existing knowledge, there is little advice for teachers regarding specific strategies to develop these ideas so that they become more 'scientific', particularly in a class in which there might be up to 30 alternative frameworks for each concept!

Harlen (1996) commented that it might appear too difficult to find out about the ideas of all the children in a class in such a way as to plan activities to accommodate them. In addition, traditional ideas of teachers, school boards, principals and parents are also deep-rooted and difficult to change. Implementation of constructivist approaches in the classroom may therefore be subject to some resistance. Indeed Cohen et al (1996) claimed that the constructivist view of learning totally 'turned its back' on the view of progression embedded in the National Curriculum, which assumes that all children learn in the same sequence. Solomon (1994) claimed that constructivism is not congruent with the kind of learning that takes place in most

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classrooms, whilst Harlen (1996) reported that quite often everyday events do, in fact, conform to **non-scientific** ideas. Keogh and Naylor (1996) revealed that analysis of the 'hands-on' approach indicated that pupils spent little or no time planning and interpreting their findings, and suggested that a 'minds-on' approach is also required to enable the children to make sense of a concept by relating it to their own experience. Osborne (1997) asked provocatively: "[Is doing science the best way to learn science?](#)"

In spite of these criticisms the constructivist approach to science teaching in primary and post-primary schools is widely advocated and promoted worldwide. Indeed, the South Australian Curriculum Standards and Accountability Framework, from birth to year 12, uses "[a conception of learning which is drawn from constructivist learning theories](#)" to guide the formulation of its new curriculum framework (SACSA 2000).

Children's interest in science is also vital for effective science learning, particularly in developing their confidence in dealing with science in terms of curiosity and methodical inquiry. When children reach the post-primary school, they will have experienced seven years of schooling and by this stage will have developed their own attitudes to science. Murphy and Beggs (2003a) carried out an extensive survey of primary children's attitudes to science and found that most of the older pupils (10-11 years) had significantly **less** positive attitudes than younger ones (8-9 years) towards science enjoyment, even though the older pupils were more confident about their ability to do science.

The effect of age on pupils' attitudes was far more significant than that of gender.

Girls were, however, more positive about their enjoyment of science and were a lot more enthusiastic about how their science lessons impacted upon their environmental awareness and how they kept healthy. There were also a few significant differences in the topics liked by girls and boys – generally girls favoured topics in the life sciences and boys preferred some of the physical science topics. In an attempt to improve children's experience of science in primary school, Murphy, Beggs and Carlisle (2003, in press) report that increasing the amount of practical, investigative work in science, particularly when children are using ICT, had a marked, positive effect on their enjoyment of science. They demonstrated a highly significant reduction in the effects of age and gender on children's science attitudes.

Other research into children's learning in science being carried out in the last decade has focused on the role of the primary teacher. Many findings, for example Harlen et al (1995), have pointed towards problems linked to primary teachers' insufficient scientific knowledge background and their lack of confidence in teaching science. Some studies have criticised the level of the content of some areas of primary science. Murphy, Beggs et al (2001) showed that even third level students, including those who experienced compulsory school science from the ages of 11-16 and some with post-16 science qualifications, could not correctly answer questions in some primary science topics in tests, which had been written for 11 year-olds.

These problems, when taken together with the emphasis of national tests on content knowledge, may have contributed to

science frequently being taught as facts or as a 'body of knowledge' in the final two years of primary school. Teachers feel the need to prepare children for the tests by ensuring that they can recall the required content knowledge. Attention to constructivist theories of learning science and to scientific enquiry has diminished by this stage. Ponchaud (2001) indicated that further pressures on UK primary teachers that militate against their delivery of good science teaching may include the recent government initiatives in literacy and numeracy, which have resulted in the timetabling of science as short afternoon sessions in many schools.

When considering 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. When 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 (McCullough, personal communication). These physical changes taking place in the brain 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).

This model of learning predicts that active learning, such as that promoted by constructivist teaching approaches, in which children are engaged in knowledge construction, enables more pervasive neural connectivity and hence enhanced science learning. The use of ICT can facilitate more constructivist teaching in the primary school. One of the principal problems a teacher faces when using constructivist approaches to science teaching is the consideration of the unique ideas and experiences 30 individuals bring to each new science topic. How can the teacher elicit and challenge all of these to ensure that children develop the desired scientific concepts? How can s/he ensure that each child is involved in science investigation? How can s/he promote group work with limited science resources and/or space so that children can co-operate in science projects?

CURRENT USE OF ICT IN PRIMARY SCIENCE

The term ICT embraces a range of technologies broadly concerned with information and communication. The popular idea of ICT hardware in the classroom or computer suite includes one or more multimedia desktop computers or laptops and a combination of the following: digital camera, printer, scanner, CD-writer, data projector, interactive whiteboard, robot and, in science classes, data loggers and perhaps a digital microscope. There will be a range of software available on the hard drive of the computers and as add-ons (usually as floppy discs or CD-Roms). The machines



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may or may not be networked or have access to the Internet. How these facilities might improve the learning and teaching of primary science in terms of the development of the scientific skills, concepts and attitudes outlined in Section 2.1 is summarised below in Table 1.

ICT can support both the investigative (skills and attitudes) and more knowledge-based aspects (concepts) of primary science. The more recent approaches to science learning, particularly the social constructivist methodologies (see section 1.2 on children's learning in science), 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, however, 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.

Perhaps it is early days. Primary science has only been part of the National Curriculum in the UK for little more than a decade, so most teachers who qualified before its introduction will have received no science training in their initial teacher education and perhaps only minimal INSET science training. Many teachers, therefore, have yet to come to grips with how to teach

Table 1: Summary of the goals of primary science learning

Skills

- observation
- communication
- measurement
- experimenting
- classifying
- interpreting data
- making hypotheses
- inference
- prediction
- controlling & manipulating variables

Concepts

- time
- life cycles
- weight
- interdependence of living things
- length
- change
- volume
- adaptation
- energy
- properties of materials

Attitudes

- perseverance
- originality
- co-operation
- responsibility
- curiosity
- independence of thinking
- self-criticism
- open-mindedness

science effectively before they can conceptualise how using ICT can enhance the teaching of 'good' science in the

primary school. Researchers also have little access to classrooms where they can carry out systematic investigation of practice.

IDENTIFICATION OF RESEARCH AREAS TO EXPLORE HOW ICT USE CAN ENHANCE PRIMARY SCIENCE LEARNING

Some of the questions raised in this review point towards gaps in the research into primary science and ICT. For example in section 3.3 on primary teachers' knowledge of science, the question is raised as to whether aspects of primary science are too difficult for the teachers, let alone the children. More research is needed to determine which aspects of science are appropriate for primary children to learn. Clearly, if not taught properly, children can enter post-primary education more confused than informed about some science topics. This leads to greater learning and teaching problems at secondary level than if children had never been introduced to such topics previously.

In relation to the role of ICT enhancing children's science learning (section 3.5) the question is raised about how ICT use can aid the constructivist approach to science teaching. Most particularly, there is a huge 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?

In section 4.1, in which 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 respectively? Indeed, do we need to acquire such skills in order to interpret, interrogate and manipulate data successfully? This is a huge question and a vital one in relation to the use of ICT in primary science. If, for example, graph drawing skills are found not to be required for successful graphical interpretation, then ICT use can substitute for 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 (graph, for example) was produced.

When exploring the use of ICT as a reference source, section 4.2 presents reactions of student teacher users to 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.

CONCLUSION

This report summarises research in primary science and in the classroom use of ICT. It highlights the separation of these areas and the 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.

is content-free software most useful in helping children to 'construct' and communicate ideas?

INTRODUCTION TO REVIEW



for primary children, scientific literacy refers to the knowledge and skills required to gain a basic knowledge and understanding of science

1 INTRODUCTION TO REVIEW

This review focuses on the development of primary science since it was first introduced as a compulsory, core subject in the primary curriculum in England and Wales (1989). In a review of the first ten years of compulsory primary science, Wynne Harlen (1998) identified current concerns as: the teacher's role in constructivist learning, teachers' subject knowledge, the balance between process skills and science content, and the need for greater understanding and application of formative assessment. She anticipated that the foremost foreseeable change in the learning and teaching of primary science over the next ten years would be the impact of information and communications technology (ICT).

This review will consider the impact of ICT in primary science in relation to the areas identified by Harlen (1998) and provide a critical evaluation of ways in which ICT is currently being used to promote good science teaching. It will reflect on the science and ICT 5 year-old children of today need to learn to enable them to become scientifically and computer-literate by the time they are 20. Yapp (2003) considered this issue and suggested that primary education should provide children with more languages, scientific and technological awareness and confidence, cultural sensitivity and media awareness. The skills these children develop should include team working, creativity, innovation and learning how to learn. Informal learning should be valued as much as formal learning (Yapp 2003).

SCIENTIFIC LITERACY

There is much debate about what constitutes scientific literacy and about the nature of science that should be taught at school (Murphy et al 2001). The term 'scientific literacy' has been used variously as a definition, a slogan or as a metaphor (Bybee 1997). As a definition, the term 'scientific literacy' may be used to facilitate discourse, for description and explanation, or to embody a programme of action (Scheffler 1960). When used as a slogan 'scientific literacy' serves to unite science educators behind a single statement representing the purpose of science education. As a metaphor, the term 'scientific literacy' refers to being well educated and well informed in science, as opposed to merely understanding scientific vocabulary.

Bybee (1997) suggests a broad framework, which describes certain thresholds that identify degrees of scientific literacy (Fig 1). Within that framework an individual may demonstrate several levels of literacy at once depending on the context, the issue and the topic.

While the term 'scientific literacy' has been used for the past 40 years in the USA, it is not so common in the UK. Hurley (1998) states that scientific literacy is known as 'public understanding of science' in the UK. In this report the term 'scientific literacy' refers to the minimal scientific knowledge and skills required to access whatever scientific information and knowledge is desired. For primary children, therefore, scientific literacy refers to the knowledge and skills required to gain a basic knowledge and understanding of science as exemplified by the development of a range of process skills,

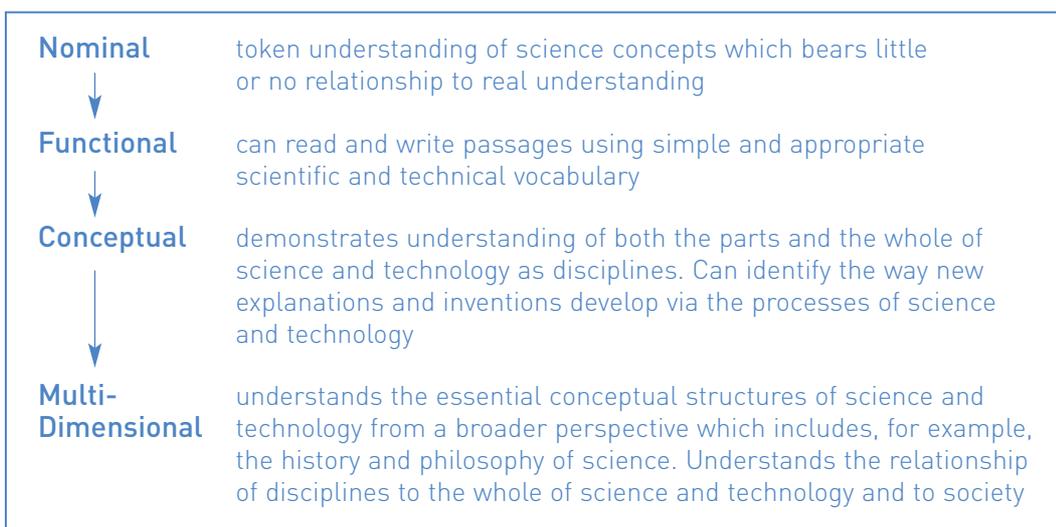


Fig 1: Degrees of scientific literacy [adapted from Bybee 1997]

the acquisition of various scientific concepts, and the formation of particular attitudes (See Section 2.1). In addition children should have the knowledge and skills to attain the required targets laid down in national curricula. In Bybee's framework, therefore, scientific literacy for primary children would be demonstrated mostly at the functional with elements of the conceptual levels.

The issue of **what** science should be taught has been debated widely over the past 15 years. In 1985 the American Association for the Advancement of Science (AAAS) launched a long-term effort to reform science, mathematics and technology education, referred to as Project 2061. It was so named because the project's originators were considering all the science and technology changes that a child entering school in 1985 – the year Halley's comet was in view – would witness before the return of the comet in 2061 (Nelson 1998). This project set out to identify what was most important for the

next generation to know and to be able to do in science, mathematics and technology – that is, what would make them scientifically literate. Some of its guiding principles were that:

- science literacy consists of: knowledge of certain important scientific facts, concepts, and theories; the exercise of scientific habits of mind; and an understanding of the nature of science, its connections to mathematics and technology, its impact on individuals, and its role in society
- for students to have the time needed to acquire essential knowledge and skills of science literacy, the sheer amount of material that today's science curriculum tries to cover must be significantly reduced
- effective education for science literacy requires that every student be frequently and actively involved in exploring nature in ways that resemble how scientists themselves go about their work.

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SCIENCE IN THE PRIMARY SCHOOL



the curriculum should be re-designed to enhance general scientific literacy as opposed to the current curriculum, which is geared towards the small proportion of pupils who will become scientists

The contemporary science curricula in the US were considered to be 'overstuffed and undernourished' (Nelson 1998). A prescriptive set of specific learning goals (benchmarks) from kindergarten to year 12 was recommended in 'Benchmarks for Science Literacy' (AAAS 1993) which suggested reasonable progress towards the adult literacy goals laid out in a sister report 'Science for All Americans' (AAAS 1990).

In the UK it has also been recognised that there is still an over-emphasis on content in the school science curriculum. Much of this content is isolated from the contexts, which could provide relevance and meaning. Further problems include the lack of an agreed model for the development of pupils' scientific capability from the age of 5 upwards, and the fact that assessment in science is geared towards success in formal examinations (Reiss, Millar and Osborne 1999). A two-year study, 'Beyond 2000' (Nuffield Foundation 1998), made ten recommendations regarding the implementation of the Science National Curriculum in England and Wales. Essentially, it is suggested that the curriculum should be re-designed to enhance general scientific literacy as opposed to the current curriculum, which is geared towards the small proportion of pupils who will become scientists. A recent report from OFSTED (1996) stated that:

"Most pupils acquire a sound factual knowledge of the material in the Programme of Study but their understanding of the underlying scientific concepts often remains fragmentary... as the content of science becomes conceptually more demanding, there is a

progressive polarisation of pupils' achievement, with the least able often becoming confused and holding incorrect ideas."

2 SCIENCE IN THE PRIMARY SCHOOL

2.1 WHAT IS PRIMARY SCIENCE AND WHY IS IT IMPORTANT?

Primary science is concerned with three broad areas: energy and forces; materials; and living things, which lay the foundations for physics, chemistry and biology respectively. Whilst these are the broad areas of study, primary science is not just concerned with knowledge, but particularly with the scientific method and the effect of the use of this method on the individual child. It is child active, developing both manipulative and mental activity. It is child focused, concentrating on an aspect of the world the child experiences and something in which the child can display an interest.

Science is currently one of the three core subjects in the primary curriculum and, together with English and mathematics, is formally assessed at the end of primary schooling in England and Wales, and it is part of the Transfer Procedure Test, which is taken in the final year of schooling by those pupils who wish to attend grammar schools in Northern Ireland.

Primary science has three 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 five senses.
- 2 Communication - the ability to say clearly through many media, eg written, verbal, diagrammatic, presentation software, what has been discovered or observed.
- 3 Measurement - measurement is concerned with comparisons of size, time taken, areas, speeds, weights, temperatures and volumes. Comparison is the basis of all measurement.
- 4 Experimenting - 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 Classifying - children need to recognise, sort and arrange objects according to their similarities and differences.
- 7 Interpreting data - the ability to understand and interpret the information a child collects.
- 8 Making hypotheses - 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 and following careful study, a child would draw a conclusion that fits all the observations he or she has made.
- 10 Prediction - foretelling the result of an investigation on the basis of consistent, regular information from observations and measurements.
- 11 Controlling and manipulating variables - the careful control of conditions in testing which may provide a fair test and give valid results.

While 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

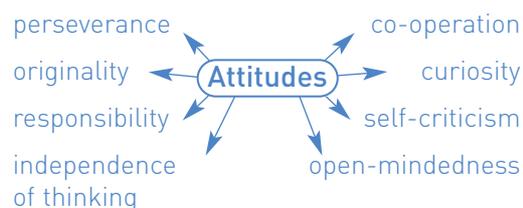
Examples of concepts fostered by primary science learning are:

time	life cycles
weight	interdependence of living things
length	change
volume	adaptation
energy	properties of materials

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

Attitudes

Science can also develop a child's character. Specific attitudes which are highly treasured by teachers and society and which can be achieved through hands-on, discovery-based investigations include:



SCIENCE IN THE PRIMARY SCHOOL



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: Sc1 - Scientific Enquiry, Sc2 - Life Processes and Living Things, Sc3 - Materials and their Properties and Sc4 - Physical Processes (DfEE 1995). 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: AT1 – Exploring and Investigating in Science and Technology, and AT2 – Knowledge and Understanding (DENI 1996). The skills areas are: planning, carrying out and 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.

2.2 HOW DO CHILDREN ACQUIRE THESE SKILLS, CONCEPTS AND ATTITUDES?

What these processes might mean in terms of the child's way of working can be explained as:

- 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

The teacher has a vital role in this process and this can be developed by:

- 1 Helping pupils to raise questions and suggest hypotheses.
- 2 Encouraging children to predict and say what they think will happen.
- 3 Encouraging closer and more careful observation.
- 4 Helping children to see ways in which their tests are not fair and ways to make tests fairer.
- 5 Encouraging pupils to measure whenever it is useful.
- 6 Helping pupils to find the most useful ways of recording evidence so that they can see patterns in their observations.
- 7 Encouraging children to think about their experiences, to talk together and to describe and explain to others.
- 8 Helping children to see the uses they can make of their findings.

RESEARCH INTO CHILDREN'S LEARNING IN SCIENCE



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.

3 RESEARCH INTO CHILDREN'S LEARNING IN SCIENCE

Research on children's learning in science over the past 30 years has been influential in primary science teaching in the UK, particularly since the introduction of compulsory science for all children between the ages of 5 and 16. The National Curriculum for England and Wales, 5-14 National Guidelines in Scotland and the Northern Ireland Curriculum were all introduced in the late 1980s and early 1990s. These defined for the first time what aspects of science should be taught at primary level. Decisions regarding the content and pedagogy of primary science were made using evidence from major research projects. The Assessment of Performance Unit (APU) surveyed children's science knowledge at the ages of 11, 13 and 15 during the 1970s and 1980s, and outlined what these children should be expected to do in science.

Two other projects were influential. The SPACE (Science Processes and Concepts Exploration) project (1990-98) investigated children's scientific ideas and the STAR (Science Teaching Action Research) project studied classroom practice in relation to process skills. Harlen (p25 in Sherrington, 1998) has discussed the impact of these projects. In summary, they - together with other international projects - generated major interest in children's own scientific ideas, which has given weight to constructivist approaches towards learning in science.

3.1 CONSTRUCTIVISM AND CHILDREN'S ALTERNATIVE CONCEPTIONS

Constructivism has its roots in psychology, philosophy, sociology and education. Its central idea is that human learning is 'constructed' – learners build on the foundations of previous knowledge. Learning is therefore an active, rather than a passive process. Constructivism has major implications for science teaching; it calls into question the traditional, 'utilitarian' practices and places the child at the centre of the learning process. The popularity of constructivist approaches to science teaching has been steadily increasing over the past 30 years.

The constructivist teaching approaches are based on the work of psychologists and educators such as Rousseau, Dewey, Piaget, Bruner and Vygotsky, all of who believed that children build on their experiences as they mature and that the child is the centre of the learning process. Rousseau (1712-1778) proposed that the curriculum should be built around the child's interests – perhaps a more feasible proposal in the days before mass schooling. Rousseau suggested that children learn best by direct experience, activity and discovery and that the teacher's role is one of facilitation. Dewey (1859-1953) also stressed the importance of hands-on experience to children's learning. He believed that the natural, spontaneous activities of children could be directed towards educational ends and that this was most successful when children were given problems to solve.

Piaget and Bruner's work contributed towards the 'cognitive constructivism' paradigm, whereas Vygotsky is associated



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more with 'social constructivism'. Cognitive constructivism refers to the developmental stages identified by Piaget that children pass through as they construct meaning based on their experiences.

Bruner's studies built on Piaget's developmental stages and postulated that children build on what they already know in a spiral manner – he suggested there was no limit to what they can learn. Social constructivism embraces the importance of peers and teachers in children's learning.

Vygotsky proposed the concept of the 'zone of proximal development', which described the gap between what a child could do or learn alone and what s/he could do or learn with help. The role of the teacher, according to Vygotsky, is elevated beyond 'facilitator' to that of an active participant who guides, encourages and supports children as they engage in problem-solving activities.

The constructivist view of learning suggests that children come to class with alternative frameworks (already formed ideas and ways of thinking) about a range of scientific phenomena. Their learning depends not only on the learning environment as set up by society, school and teachers, but also on their prior knowledge, attitudes and aspirations. Learners already have a vocabulary of words with meanings which can frequently be at variance with those used by scientists, for example: animal, flower, living, force and energy.

In a study of concept formation by 5-7 year-old children, Murphy (1987) recorded the responses of 280 children from 33 schools to 25 terms commonly used in science. They were asked to describe a word (without using it) so that the other children in the class might guess the correct word. A few of these responses are presented in Table 2.

Table 2: Young children's conceptions of various terms used in science

Word	Child's response	Author's interpretation
Animal	<p>A giraffe, a lion, a tiger or a sheep... They make different noises from us and they are a different shape. They have four legs. (5/6 years old)</p> <p>It's not like us. It's something else different from us. Some can be hairy or woolly. It can be black and white or brown. (6/7 years old)</p> <p>A pig, a cow. I'm not one of these. I haven't got four legs. (6/7 years old)</p> <p>It's horses and cows and sheep and dogs and pigs... it has four legs and we have two. (6/7 years old)</p>	No conception of humans being 'animals' – children emphasise differences between people and animals.
Flower	<p>It has a stem, petals, a root, nice smell. (6/7 years old)</p> <p>You grow it with seeds. The shoots come up. Comes up in the spring. You plant it in winter. They are yellow, purple, red, blue. (5/6 years old)</p>	Flower is the whole plant.

Word	Child's response	Author's interpretation
Living	You do this in your house. (5/6 years old) You eat, watch television; a bed to sleep in. You play with your toys. (5/6 years old) People do this in a house. Bird in a cage. Dog in a kennel. (5/6 years old)	Has resonance with the biological concept of a 'niche', which is 'activity within a habitat'.
Energy	You have this in your legs to run fast – to lift a weight you have to have it – if you're climbing a building you'd have to have it in your hands. Cats have it in their eyes. (6/7 years old) Use it to power car/lorries/tractors. Comes through electric wires into houses. (6/7 years old)	Energy as an entity.
Force	You make somebody do something they mightn't want to do and you just make them do it... If the door was stuck you would try to do this to make it open. (6/7 years old) Gravity is a force that pulls you to the ground... There are forces in spacecraft and you float. (6/7 years old)	Force as power. A force acts to make you weightless...

There is much evidence to suggest that some of these alternative frameworks persist, even in individuals who have studied science to degree level and beyond. Wandersee, Mintzes and Novak (1994), in their review of research on alternative conceptions in science cite several examples, for instance, a film 'A Private Universe' which revealed the persistent fundamental misunderstanding of Harvard graduates about the solar system (Pyramid Film and Video, 1988). A familiar example in life sciences is plant nutrition. Wandersee's (1983) survey of some 1,400 subjects showed that 60% of school and 50% of college students stated that plants obtain most of their food from the soil.

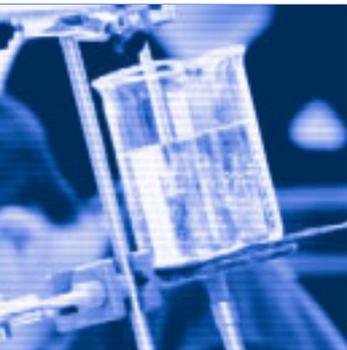
Millar and Driver (1987) pointed out the importance of the teacher's role in

introducing scientific concepts. They reiterated the view that many of the difficulties experienced by students learning science had their origins within particular areas of subject matter.

Children and students can learn by rote to memorise enough information to pass a test, or they can be trained to recognise particular diagrams or systematic representation and to respond in the appropriate manner. This type of learning, however, does not lead to sufficient understanding of the material to be applied outside the classroom; nor does it enable the level of understanding required to explain the phenomenon to other learners. Activities such as enquiry, investigation and problem solving when carried out collaboratively and accompanied by effective teacher dialogue

activities such as enquiry, investigation and problem solving when carried out collaboratively can bring about understanding of scientific concepts

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can bring about understanding of scientific concepts. It is in the enhancement of these types of activities promoted by a constructivist approach to science teaching, as opposed to the 'drill and practice' type of computer-based learning that will be most beneficial for the primary science classroom.

Criticisms have been levelled against the constructivist approach to science teaching in the primary school. The most frequently quoted of these is that whilst the research advises that teachers identify children's alternative frameworks, there is little advice for teachers regarding specific strategies to develop these ideas so that they become more 'scientific', particularly in a class in which there might be up to 30 alternative frameworks for each concept! Harlen (1996) commented that it might appear too difficult to find out about the ideas of all the children in a class in such a way as to plan activities to accommodate them. In addition, traditional ideas of teachers, school boards, principals and parents are also deep-rooted and difficult to change.

Implementation of constructivist approaches in the classroom may therefore be subject to some resistance. Indeed Cohen et al (1996) claimed that the constructivist view of learning totally 'turned its back' on the view of progression embedded in the National Curriculum, which assumes that all children learn in the same sequence. Solomon (1994) claimed that constructivism is not congruent with the kind of learning which takes place in most classrooms, whilst Harlen (1996) reported that quite often everyday events do, in fact, conform to **non-scientific** ideas. Keogh and Naylor (1996) revealed that analysis of the

'hands-on' approach indicated that pupils spent little or no time planning and interpreting their findings, and suggested that a 'minds-on' approach is also required to enable the children to make sense of the concept by relating it to their own experience. Osborne (1997) asked provocatively: "[Is doing science the best way to learn science?](#)"

In spite of these criticisms, the constructivist approach to science teaching in primary and post-primary schools is widely advocated and promoted worldwide. Indeed, the South Australian Curriculum Standards and Accountability Framework, from birth to year 12, uses "[a conception of learning which is drawn from constructivist learning theories](#)" to guide the formulation of its new curriculum framework (SACSA 2000).

3.2 CHILDREN'S INTEREST AND ATTITUDES TOWARDS SCIENCE

Children's interest in science is also vital for effective science learning, particularly in developing their confidence in dealing with science in terms of curiosity and methodical inquiry. When children reach the post-primary school, they will have experienced seven years of schooling and by this stage will have developed their own attitudes to science.

Murphy and Beggs (2003a) carried out an extensive survey of primary children's attitudes to science and found that most of the older pupils (10-11 years) had significantly **less** positive attitudes than younger ones (8-9 years) towards science enjoyment, even though the older pupils were more confident about their ability to do science.

children's interest in science is vital for effective science learning

The effect of age on pupils' attitudes was far more significant than that of gender. Girls were, however, more positive about their enjoyment of science and were a lot more enthusiastic about how their science lessons impacted upon their environmental awareness and how they kept healthy. There were also a few significant differences in the topics liked by girls and boys – generally girls favoured topics in the life sciences and boys preferred some of the physical science topics. In an attempt to improve children's experience of science in primary school, Murphy, Beggs and Carlisle (2003, in press) report that increasing the amount of practical, investigative work in science, particularly when children are using ICT, had a marked, positive effect on their enjoyment of science. They demonstrated a highly significant reduction in the effects of age and gender on children's science attitudes.

A study by the Institute of Electrical Engineers (1994) showed a decline in the level of interest in science in England between the ages of 10 and 14. Osborne, Driver and Simon (1998) found that positive attitudes towards school science appeared to peak at or before the age of 11 and decline thereafter by quite significant amounts, especially in girls. They revealed that science attitudes and interests are developed early in primary school and these are carried into secondary school and adulthood.

There has been concern over the low level of uptake of science by post-16 pupils for nearly half a century. Several researchers have indicated that part of the reason for this is that pupils are 'turned off' science at school when they are quite young. Most agree that the erosion in pupils' interest in

school science occurs between the ages of 9 and 14 (for example, Hadden and Johnstone 1983, and Shibeci 1984), even though they retain positive attitudes towards science generally and acknowledge its importance in everyday life.

The problem of declining interest in school science is international and many reasons have been put forward to explain it, including the transition between primary and post-primary schooling, the content-driven nature of the science curriculum, the perceived difficulty of school science and ineffective science teaching, as well as home-related and social-related factors. It is hoped that the development of ICT in primary science will add to pupil interest and motivation so that children's curiosity and desire for understanding will enhance their science learning.

3.3 TEACHERS' SUBJECT KNOWLEDGE

Other research into children's learning in science being carried out in the last decade has focused on the role of the primary teacher. Many findings, for example Harlen et al (1995), have pointed towards problems linked to primary teachers' lack of confidence in teaching science and their insufficient scientific knowledge background. Some studies have criticised the level of the content of some areas of primary science. Murphy, Beggs et al (2001) showed that even third level students, including those who experienced compulsory school science from the ages of 11-16 and some with post-16 science qualifications, could not correctly answer questions in some primary science topics in tests, which had been written for 11 year-olds.

the problem of declining interest in school science is international

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we advocate that the content of the primary curriculum is changed to enable teachers to give an exciting, comprehensible introduction

These problems, when taken together with the emphasis of national tests on content knowledge, may have contributed to science frequently being taught as facts or as a 'body of knowledge' in the final two years of primary school. Teachers feel the need to prepare children for the tests by ensuring that they can recall the required content knowledge. Attention to constructivist theories of learning science and to scientific enquiry has diminished by this stage. Ponchaud (2001) indicated further pressures on UK primary teachers that militate against their delivery of good science teaching may include the recent government initiatives in literacy and numeracy, which have resulted in the timetabling of science as short afternoon sessions in many schools.

Is some of the primary science curriculum too hard for teachers, never mind pupils? Some findings from the Office for Standards in Education (OFSTED 1995) were that:

"Some teachers' understanding of particular areas of science, especially the physical sciences, is not sufficiently well developed and this gives rise to unevenness of standards, particularly in years 5 and 6 (age 10 and 11).

In the upper years of Key Stage 2 (which represents age 7-11 year-old children) shortcomings in teachers' understanding of science are evident in the incorrect use of scientific terminology and an overemphasis on the acquisition of knowledge at the expense of conceptual development."

Harlen (1997) was also concerned about international findings, which reported pupil difficulties within certain concept areas.

She summarised findings from a large number of studies and concludes that pupil difficulty is chiefly due to the insufficient explanations given by primary teachers. It is interesting to note that virtually all the published evidence cites difficulties with the physical sciences, whereas in the Murphy and Beggs (2003a) study, which asked children for their views, 'the flower' was most frequently cited as the most difficult part of science. This could be due to a concentration on 'learning the parts' as opposed to learning about the process. Osborne and Simon (1996) demonstrated that primary pupils' explanations of 'how we see' were considerably better when a science specialist had taught them.

We advocate that the content of the primary curriculum is changed to enable teachers to give an exciting, comprehensible introduction. Primary teachers should work with children in the **observation and description** of phenomena such as evaporation and gravity but save any explanation for post-primary science. In the life sciences, primary children could be introduced to the lives of plants and animals, using challenging examples to stimulate their interest and curiosity, as opposed to naming relatively obscure flower or body parts (for example, **ovule** and **scapula**). The author of this report strongly recommends that primary children should not be taught aspects of science that are too difficult for their teachers.

Primary teachers look towards aspects of ICT to help them with their science teaching. Indeed, during a Becta (British Educational Communications and Technology Agency) Science CD-Rom road show, teachers were asked to evaluate the

resources which were available for demonstration. Issues relating to CD-Roms which were aimed at Key Stage 2 children (7 to 11 years) that were commented upon included: "most suited to individual use rather than the whole class", "would need to be supported by worksheets to direct pupils", "detailed knowledge required to use." "limited interaction for pupils". Frequently it appears that insufficient formative evaluation of courseware products is carried out during the design and implementation phases, resulting in software which is less suited to the target audience than it is to the developer.

3.4 THE PRIMARY SCIENCE CURRICULUM AND ITS ASSESSMENT

The current primary science curriculum and the way it is taught and assessed has been criticised by many as constraining children's science learning as a body of facts rather than as a method of enquiry which requires innovation and creativity. Ponchaud (2001) was concerned that scientific enquiry has diminished in many primary schools. He pointed out that teachers should capitalise on the flexibility of the primary curriculum to carry out longer-term experiments, which would be more difficult to do in the timetable-constrained post-primary school. Campbell (2001) and Ponchaud (2001) also found that, when asked about what they liked best in science, primary children most frequently replied "doing experiments" and "finding out new things". Bricheno (2000) cited the importance of small group practical work and using ICT in promoting positive attitudes to science. The Murphy and Beggs (2003a) study also found that children liked doing

experiments best in science. The reasons given included that doing experiments was fun, that they found out things and that they were learning whilst enjoying themselves. One 11 year-old boy commented that when doing experiments he could do things for himself, which helped him remember "new things". A girl of the same age stated that practical science was "a better way to understand things rather than just writing them down". Even an 8 year-old suggested that doing experiments "encourages your mind". Children, therefore, were telling us how important practical, experimental science was for their learning.

Preparation for national science tests in primary school could also impact negatively on children's learning in science. Ponchaud (2001) reported that anxiety about performance in national tests sometimes leads to excessive routine test preparation in the final years of primary school. Children have reported the boring and repetitive nature of such preparation (Murphy and Beggs 2003a) and commented negatively on aspects of curriculum content which they found difficult, such as:

"The flower – remembering parts, like ovule and ovary – I kept getting these terms mixed up" (11 year-old girl)

"Forces – pushing, colliding, hard to understand where the force is acting from" (10 year-old boy)

"Evaporation – I was confused by all the long words, like evaporation, condensation" (11 year-old girl)

doing experiments was fun, they found out things and were learning whilst enjoying themselves

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the ability to make connections between apparently unrelated ideas lies at the heart of early scientific learning

3.5 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 travel². 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 (McCullough, personal communication). The physical changes taking place in the brain 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).

This model of learning predicts that active learning, such as that promoted by constructivist teaching approaches, in which children are engaged in knowledge construction, enables more pervasive neural connectivity and hence enhanced science learning. The use of ICT can facilitate more constructivist teaching in the primary school. One of the principal

problems a teacher faces when using constructivist approaches to science teaching is the consideration of the unique ideas and experiences 30 individuals bring to each new science topic. How can the teacher elicit and challenge all of these to ensure that children develop the desired scientific concepts? How can s/he ensure that each child is involved in science investigation? How can s/he promote group work with limited science resources so that children can co-operate in science projects?

McFarlane (2000a) illustrated the relationship between the use of ICT and the development of children's science skills (see Fig 2).

McFarlane's (2000a) scheme already seems 'dated' due to the absence of reference to PowerPoint or interactive whiteboards, both of which have become used routinely in many classrooms over the past three years. Perhaps the approach towards integration of ICT into primary science should focus more on generic, as opposed to specific ICT applications, for example: content versus content-free software, data logging, information handling and control technology. Which types of application are best suited towards the development of the range of skills, concepts and attitudes outlined in Section 2.1?

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

² See Futurelab partner publication 'Thinking Skills, Technology and Learning' (Wegerif, 2002) for a discussion of similar technology-inspired models of learning, and for a discussion of the role of technologies in teaching thinking skills.

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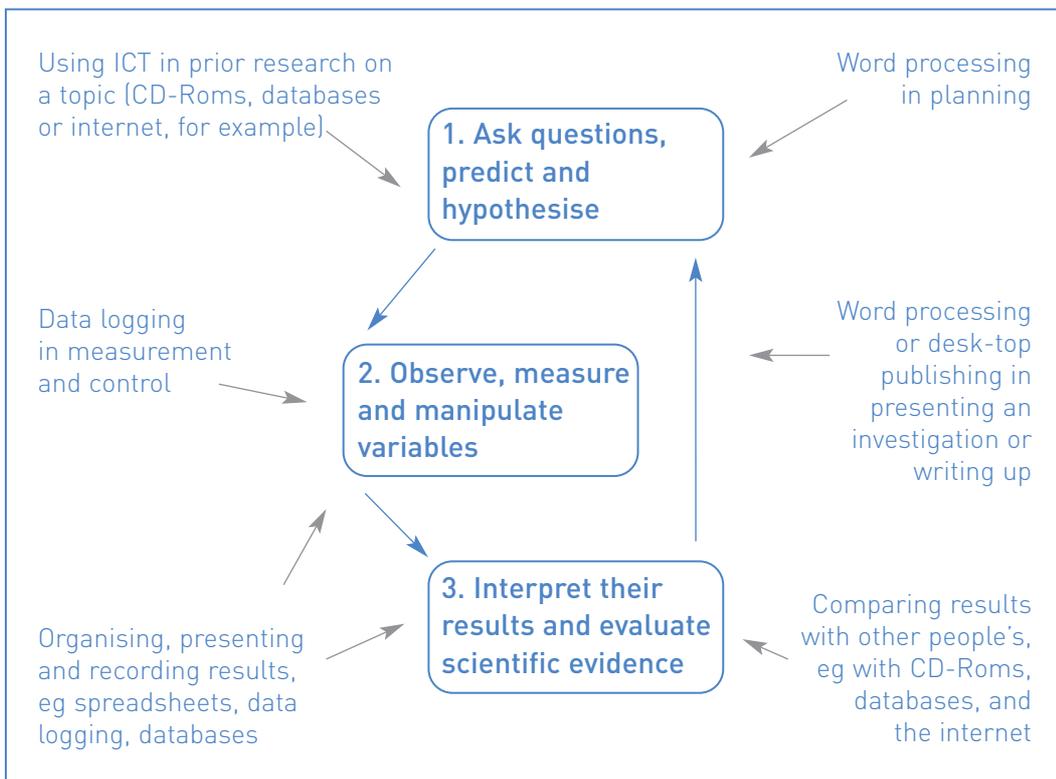


Fig 2: The relationship between the use of ICT and the development of children's science skills (McFarlane 2000a)

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 10-11 year-old children creating PowerPoint presentations to demonstrate and communicate their understanding of electric circuits. The following section evaluates different ways ICT is currently being used to support primary science in terms of how effectively ICT promotes 'good' science in terms of skill, concept and attitude development.

4 CURRENT USE OF ICT IN PRIMARY SCIENCE

4.1 WHAT IS THE ROLE FOR ICT IN PRIMARY SCIENCE?

The term ICT embraces a range of technologies broadly concerned with information and communication. The popular idea of ICT hardware in the classroom or computer suite includes one or more multimedia desktop computers or laptops and a combination of the following: digital camera, printer, scanner, CD-writer, data projector, interactive

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whiteboard, robot and, in science classes, data loggers and perhaps a digital microscope. There will be a range of software available on the hard drive of the computers and as add-ons (usually as floppy discs or CD-Roms). The machines may or may not be networked or have access to the internet. How these facilities might improve the learning and teaching of primary science in terms of the development of the scientific skills, concepts and attitudes outlined in Section 2.1 is summarised in Table 3.

ICT can support both the investigative (skills and attitudes) and more knowledge-based aspects (concepts) of primary science. The more recent approaches to science learning, particularly the social constructivist methodologies (see section 1.2 on children's learning in science), 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. Perhaps it is early days. Primary science has only been part of the National Curriculum in the UK for little more than a decade, so most teachers who qualified

Table 3: Summary of the goals of primary science learning

Skills

- observation
- communication
- measurement
- experimenting
- classifying
- interpreting data
- making hypotheses
- inference
- prediction
- controlling & manipulating variables

Concepts

- time
- life cycles
- weight
- interdependence of living things
- length
- change
- volume
- adaptation
- energy
- properties of materials

Attitudes

- perseverance
- originality
- co-operation
- responsibility
- curiosity
- independence of thinking
- self-criticism
- open-mindedness

before its introduction will have received no science training in their initial teacher education and perhaps only minimal INSET

ICT is used in primary science: as a tool, as a reference source, as a means of communication and as a means for exploration

science training. Many teachers, therefore, have yet to come to grips with how to teach science effectively before they can conceptualise how using ICT can enhance the teaching of 'good' science in the primary school. Researchers have little access to classrooms where they can carry out systematic investigation of practice.

The following section therefore comprises an account of instances of practice derived from different sources in which usage of ICT in various primary science contexts has been reported. 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. Second, from directing a research project funded by the AstraZeneca Science Teaching Trust (AZSTT) in which science specialist student teachers co-planned, co-taught and co-evaluated science lessons with classroom teachers. Whilst there was not an emphasis on using ICT in the AZSTT project, we audited student and teacher confidence in their use of ICT for administration, planning and teaching at various stages in the project. The data from these audits indicated a highly significant increase in students' confidence in ICT use during the project but not so for the teachers. We surmised that the science students had more opportunity to develop their ICT skills in the classroom science context by participation, whereas teachers focused more on developing their scientific knowledge and skills. A similar project, in which ICT, rather than science, was the focus for the teamwork, would undoubtedly result in increasing teachers' confidence to use ICT in their science teaching (Murphy, Beggs and Carlisle, in preparation).

4.1 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 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 in Table 2, however, it appears 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 (2000b), however, argues that using the graphing applications of spreadsheets can allow data handling exercises 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

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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) provide some guidelines for using databases in primary science and illustrate two examples. In the first, 10 year-olds are building up a database about flowers. Much of the data collected seems inappropriate for children of this age (length of anther, length of filament, length of carpel). It raises 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. The second example was a similar activity for infants who were creating a database of their class. This exercise could be viewed as more relevant and it enables children to produce bar charts and histograms for interpretation more quickly than by hand.

The most exciting use of a database with young children (6 and 7 year-olds) the author has 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.

As such, working with databases can directly enhance children's classification skills and, indirectly, could develop their powers of inference. Their conceptual knowledge could be potentially improved, depending on the context of the database, for example, using a 'leaf' database for identification, children could develop a

higher level of understanding of leaf structure which could be valuable at a later stage in their study of biology.

Data logging

Data logging is a highly versatile ICT tool for use in experimental science at any level. Higginbotham (2003) describes 6-7 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. 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, experimenting, space-time relationships, interpreting data, inference, prediction and controlling and manipulating 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 co-operative in their approach.

4.2 ICT AS A REFERENCE SOURCE

CD-Roms

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

Table 4: 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 Full 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

working with databases can directly enhance children's classification skills and, indirectly, could develop their powers of inference

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a wealth of science-related activities (reviewed by Sutton 2003). 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 (Beggs and Murphy, in preparation). Table 4 summarises some of the student 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 courseware 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. In my own experience of courseware development, I can state that packages would have looked, sounded and run completely differently in the absence of input from the children at whom they were 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 but 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 1,500 primary children and over 100 primary teachers (November 2001) reported a highly significant different mean response ($p < 0.001$), with 23% of the children claiming to use the internet often compared with only 13% of the teachers. There was no significant difference, however, between those reporting never to use the internet - 54% children and 55% teachers. In the same study, 13% of primary children responded that they often used a computer for homework (Murphy and Beggs 2003b).

The internet provides a wealth of resources for primary science learning and teaching. However, Feasey and Gallear (2001) in the ASE text 'Primary Science and Information Communication Technology', did not include a chapter on using the internet, perhaps because at this stage, Internet use in the primary classroom is so restricted. Cockerham (2001) has produced a resource called Internet Science, which details a series of activities aimed at 7-11 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

all software development should include several phases of formative evaluation by the target audiences

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. As an enhancement of investigative science learning, however, it is unlikely this type of internet-based learning is of significant use.

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 side 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).

4.3 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. 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, however, 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.

Digital camera, PowerPoint and 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



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

CURRENT USE OF ICT IN PRIMARY SCIENCE



attitudes of co-operation, perseverance, originality, responsibility, independence of thinking, self-criticism and open-mindedness can all be fostered

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 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 co-operation, 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 in its most advanced form (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.

4.4 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). Children can use ICT 'devices' such as 'Roamer' and 'Pixie' as a tool for investigation. Dorman (ibid) claims that by this means learning has moved "far from a simple model of Computer Aided Instruction and much closer to Computer Extended Thinking in which computers became objects to think with" (Papert 1980). He illustrates this point with a description of young children (3/4 year-olds) sitting in a circle and playing with a 'Roamer', sending it to each other. One child secretly programmed the robot so that before it reached the child opposite, it beeped and came back. Soon after this, other children were programming the 'Roamer' to perform all manner of electronic dances (Dorman 1999)³. The children had begun to collaborate

³ See again Futurelab Publication 'Thinking Skills, Technology and Learning' (Wegerif 2002) for an extended discussion of the use of these tools in learning.

seriously to get the most enjoyment from the robot and were learning from each other.

Simulators and virtual reality

Probably the least exploited use of ICT in primary science classrooms currently is exploration using simulators and virtual reality. An example of simulator use is illustrated in the TTA 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.

4.5 CASE STUDY OF INTEGRATING ICT INTO PRIMARY SCIENCE

The Teacher Training Agency has 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. For example in the first case study:

"There were two computers linked to a colour printer in the classroom, and the school had a separate ICT area equipped with ten computers linked in a network and a large screen for demonstration to the whole class. The teacher had some experience of working with computers and was supported by the school's ICT co-ordinator. The teacher was also supported by the school's science co-ordinator in planning this work... The teacher also discussed the project with a colleague who was doing a similar unit of work at another school. They agreed to set up e-mail communication between the pupils in their classes."

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

carrying out experiments on the computer was a good way to enable the children to predict and hypothesise

IDENTIFICATION OF SPECIFIC RESEARCH AREAS TO EXPLORE HOW THE USE OF ICT CAN ENHANCE PRIMARY SCIENCE LEARNING



how can ICT use aid the constructivist approach to science teaching?

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."

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.

5 IDENTIFICATION OF SPECIFIC RESEARCH AREAS TO EXPLORE HOW THE USE OF ICT CAN ENHANCE PRIMARY SCIENCE LEARNING

Some of the questions raised in this review point towards gaps in the research into primary science and ICT. For instance in section 3.3 on primary teachers' knowledge of science, the question is whether aspects of primary science are too difficult for the teachers, let alone the children. More research is needed to determine which aspects of science are appropriate for primary children to learn. Clearly, if not taught properly, children can enter post-primary education more confused than informed about some science topics. This leads to much greater learning and teaching problems at secondary level than if children had never been introduced to such topics previously.

In relation to the role of ICT enhancing children's science learning (section 3.5), the question is raised about how ICT use can aid the constructivist approach to science teaching. More particularly, there is a huge 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?

In section 4.1, in which 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, respectively? Indeed, do we need to acquire such skills in order to interpret, interrogate and manipulate data successfully? This is a huge question, and a vital one in relation to the use of ICT in primary science. If, for example, graph drawing skills are found not to be required for successful graphical interpretation, then ICT use can substitute for less exciting aspects of scientific investigation, for example, the manual plotting of data. If not, then the two must be used in tandem, so that children can conceptualise how the data record (graph, for example) was produced.

When exploring the use of ICT as a reference source, section 4.2 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 review 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. The pedagogical element of much software designed for use in primary science is frequently

lacking. In Section 4.2 of this report, 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 could easily 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 report suggests a set of generic pedagogical issues which developers, in consultation with subject matter experts, should address in all courseware:

- is the software (eg a CD-Rom) an appropriate delivery medium for the particular content or skill area being addressed?
- is the pedagogical approach (eg branched tutorial) the most appropriate to enhance learning of the material?
- has the navigation been fully piloted and evaluated by the target group?
- is the terminology appropriate for the target group – is there a hyperscript facility and is it sufficient?
- has the material been checked for bias towards any particular group of users?
- if the package is intended for class use, has differentiation in pupil ability levels been addressed?

the pedagogical element of much software designed for use in primary science is frequently lacking

IDENTIFICATION OF SPECIFIC RESEARCH AREAS TO EXPLORE HOW THE USE OF ICT CAN ENHANCE PRIMARY SCIENCE LEARNING



- have the developers made provision for pupils with special educational needs?
- are there measurable learning outcomes (if appropriate)?
- have the developers taken expert advice about an appropriate assessment strategy for the target group?
- are learners sufficiently motivated by this package?
- is there a voice-over? might the accent distract learners?
- are interactions fairly frequent and meaningful? Do longer periods of working with this package render the interactions repetitive and menial?
- are the graphics pleasing?
- do the graphics distract the user in any way?
- are there directions and are they clear?
- is the lesson length satisfactory?
- does the pupil fully determine the pace of learning?
- is there inclusion of a book marking facility?
- is computer anxiety minimised?

In the case of software designed specifically for primary science, developers should also ensure that courseware design addresses the aims of primary science as outlined in Section 2.1 of this report.

The implications for hardware developers highlighted in this review are many. In Section 4.1, the issue of data loggers is raised. 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. Indeed, I include a 'simple' data logging practical (in which student teachers record pH changes in dilute acids following the addition of various antacids) to demonstrate problems associated with their use. Each year we purchase new sensors and to date we have never experienced a problem-free session!

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.

In an ideal world I would also love 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 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, microscopes, are specifically designed to enhance their learning environment – why not computers?

children's books, desks, microscopes, are specifically designed to enhance their learning environment – why not computers?

CONCLUSION

This report summarises research in primary science and in the classroom use of ICT. It highlights the separation of these areas and the 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.

BIBLIOGRAPHY

BIBLIOGRAPHY

American Association for the Advancement of Science (1993).

Benchmarks for Scientific Literacy: Project 2061. New York: Oxford University Press

American Association for the Advancement of Science (1990). Science for All Americans. New York: Oxford University Press

Ausubel, DP (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

Bricheno, P (2000). Science Attitude Changes on Transition. Paper presentation at the ASE conference, Leeds

Bybee, RW (1997). Achieving Scientific Literacy: From Purposes to Practices. New York: Heinemann

Campbell, B (2001). Pupils' perceptions of science education at primary and secondary school, in: Behrendt, H, Dahncke, H et al (2001) Research in Science Education – Past, Present and Future. London: Kluwer Academic Publishers

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

Cohen, L, Manion, L and Morrison, K (1996). A Guide to Teaching Practice. London: Routledge

Department for Education (1995). Science in the National Curriculum. London: 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 (1999) Teaching Young Children. London: Paul Chapman Publishing

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

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

Greenwood, J, Beggs, J and Murphy, C Hands Up for Science! Report for Science Year, Northern Ireland

Hadden, R and Johnstone, A (1983). Secondary school pupils' attitudes to science: the years of erosion. European Journal of Science Education 5 (3), 309-318

Harlen, W (1996). The Teaching of Science in Primary Schools. London: David Fulton Publishers Ltd

Harlen, W (1997). Primary teachers' understanding in science and its impact in the classroom. Research in Science Education, 27 (3), 323-337

Harlen, W, Holroyd, C and Byrne, M (1995). Confidence and Understanding in Teaching Science and Technology in Primary Schools. Edinburgh: Scottish Council for Research in Education

Harlen, W (1998). The last ten years; the next ten years, in: Sherrington, R (1998) ASE Guide to Primary Science Education. Cheltenham: Stanley Thornes

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

Hurley, MM (1998). Science Literacy: Lessons from the First Generation [online]. New York: University of Albany, State University of New York. Available from: <http://science.coe.uwf.edu/NARST/research/Science1.htm> (accessed August 1999)

Institute of Electrical Engineers (IEE)

(1994). Views of science among students, teachers and parents in Osborne, J, Driver, R and Simon, S (1998) Attitudes to science: issues and concerns. *School Science Review*, 79 (288), 27-33

Keogh, B and Naylor, S (1996). *Scientist and Primary Schools*. Sandbach: Millgate House Publishers

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, *Science 3-13 The Past, The Present and Possible Futures*. London: Routledge Farmer

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

Millar, R & Driver, R (1987). Beyond processes. *Studies in Science Education*, 14 (9) 33-62

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

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

Murphy, C (1987). *Primary Science: Concept Formation in 5-7 year-old Children*. MEd Thesis, Belfast: Queen's University.

Murphy, C and Beggs, J (2003a). Children's perceptions of school science. *School Science Review* 84 (308) 109-116

Murphy, C, Beggs, J, Hickey, I, O'Meara, J and Sweeney, J (2001). National Curriculum: compulsory school science – is it improving scientific literacy? *Educational Research* 43, 2, 189-199

Murphy, C, Beggs, J and Carlisle, K (2003, in press). Students as 'catalysts' in the classroom: the impact of co-teaching between science student teachers and primary classroom teachers on children's enjoyment and learning of science. *International Journal of Science Education*

Nelson, GD (1998). *Science Literacy for All: An Achievable Goal?* [online]. Available from: <http://www.project2061.org/newsinfo/research/articles/opa.htm> (accessed August 1999)

Nuffield Foundation (1998). *Beyond 2000: Science Education for the Future*. London: Nuffield Foundation

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

OFSTED (Office for Standards in Education) (1995). *Science: A Review of Inspection Findings 1993/94*. London: HMSO

OFSTED (1996). *Subjects and Standards*. London: HMSO

Osborne, J and Simon, S (1996). Primary science: past and future directions. *Studies in Science Education*, 27, 99-147

Osborne, J (1997). Practical alternative. *School Science Review*, 78 (285) 61-66

Osborne, J, Driver, R and Simon, S (1998). Attitudes to science: issues and concerns. *School Science Review*, 79 (288), 27-33

Papert, S (1980). *Mindstorms: Children, Computers and Powerful Ideas*. Hemel Hempstead: Harvester Press

BIBLIOGRAPHY

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

Ponchaud, B (2001). Primary Science: Where Next? Paper presentation at the ASE conference, Surrey

Reiss, MJ, Millar, R and Osborne, J (1999). 'Beyond 2000: science/biology education for the future'. *School Science Review*, 79, 19-24

Scheffler, I (1960). *The Language of Education*. Springfield, IL: Charles C Thomas

Schibeci, R A (1984). Attitudes to science: an update. *Studies in Science Education*, 11, 26-59

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

Solomon, J (1994). The rise and fall of constructivism. *Studies in Science Education*, 23, 1-19

TTA (2003). *ITT exemplification materials: Using ICT in primary science: Using Information and Communications Technology to meet teaching objectives in primary science*. London: Teacher Training Agency

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

Wandersee, JH (1983). Students' misconceptions about photosynthesis: a cross-age study, in: H Helm and JD Novak (Eds) *Proceedings of the Second International Seminar on Misconceptions and Education Strategies in Science and Mathematics* (pp 441-466). Ithaca, NY: Department of Education, Cornell University

Wandersee, JH, Mintzes, JJ and Novak, J D (1994). Research on alternative conceptions in science. *Handbook of Research of Science Teaching and Learning*, edited by Dorothy L Gabel. New York: Macmillan Publishing, 177-210

Yapp, C (2003). *The Dynamics of Change*. Paper presentation at the UCET e-Learning Conference, Belfast, St Mary's University College



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