eScience and Education 2005: A Review[1]

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Profiles

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CHAPTER 1. INTRODUCTION

1.1 OUTLINE AND AIMS OF THE REVIEW

The purpose of this review report is twofold: firstly to provide an overview, or snapshot, of the emerging field of eScience in the context of education as it stands currently; and secondly, to consider some of its implications. In order to do this effectively, it is necessary first of all to sharpen our thinking about both eScience in the context of education, and science education more generally. A number of questions are raised, though more in the spirit of opening up discussion than of providing definitive answers. For example, what exactly do we mean when we talk about science education? Since the introduction of the National Curriculum in the 1980s, it has been taken for granted that all children learn science at school. However, the *purposes* of science education, both for the individuals concerned, and for wider society are not clear cut (Osborne and Hennessy 2003). There are (at least) two different models of science education, and each has different implications not only for science teaching and learning but also, we believe, for the future of broader public debate of scientific issues. One school of thought advocates the teaching and learning of some of the *content* of science, in the form of established scientific facts and principles. It must be said that this is currently the dominant model, enshrined for example in the National Curriculum. The other is more concerned with scientific *processes*; how science is practised. This model is receiving increased attention, largely through efforts to engage greater numbers of students in science for longer periods of time, and is exemplified in new approaches to GCSE science, such as the OCR Twenty First Century Science Course[2] . It is our belief that eScience activities of the type described in this report have greater potential to support school science falling into the latter category.

Alongside differing models of science education (in which the focus is on *what* is taught and learned), there is a need to consider *how* science learning is accomplished. We examine the implications of eScience for constructivist and social constructivist approaches to science teaching and active learning in primary schools and beyond, and consider alongside these the notion of reflective practice, where learners are provided with opportunities to reflect upon what they have learned, thus developing and consolidating newly acquired knowledge and skills. Another question raised relates to the concept of e-science itself. How do we define eScience in the context of education? It is probably fair to say that 'eScience' currently encompasses a mix of emerging technologies, at various stages of development and deployment, and as such, a range of definitions are possible. In contexts such as education, which are outside of mainstream academic and commercial science, it is a looser concept still. We review and discuss some possible definitions, and examine some of the questions that they raise.

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[2] Nuffield Curriculum Group and the University of York Science Education Group. See http://www.21stcenturyscience.org/news/n0000000710.asp

Another issue is the possibility of the broader application of eScience methodologies to other areas of the curriculum. To avoid closing down other educational possibilities before they have even arisen, we must consider whether science is unique, or whether in fact it shares certain characteristics with other curriculum areas in both the skills that it requires and in those it can help develop. Finally, we look beyond the school; children's learning in science, as in other topics, continues outside school hours. This may be formal and structured, for example as set homework; or more informal, perhaps looking for more information on a classroom topic in a book or on the Internet, watching a television programme, or taking part in a family visit to a science centre, museum or wildlife park. Parents, siblings and friends are often involved in such activities, and in some instances there is opportunity for wider community involvement. We therefore briefly consider the potential of eScience activities as instruments to engage the public in scientific topics or activities.

After raising the possibility of much broader application for educational eScience, we must again narrow our focus. Restrictions of time and resources demand that we scope this review accordingly. Although we briefly consider literature and case studies that fall outside of this age group, we concentrate mainly upon school science for students aged between 9-14 years old. We justify our particular focus on this age group (which cuts across the traditional primary/secondary boundary), below. In Chapter 2 we review some international examples that we feel offer models of innovative good practice. Our case studies in Chapter 3 are drawn entirely from UK examples. We conclude by considering some of the benefits and drawbacks of e-Science, and highlighting possible future research directions in this area.

We draw from many sources in this report, but would like to call initial attention to three important documents. Firstly, the Government White Paper *Excellence and Innovation: A Science and Innovation Policy for the 21st Century* (June 2000)[3], which calls for better education for all in science, and a widening of opportunities for young people to pursue a science career. One stated concern is that young people appear to lose interest in science early on, with large numbers dropping out of science subjects at the end of the compulsory period, rather than going on to study them at 'A' level and University. The authors report that the time around the transition from primary to secondary education is a danger period when children are likely to lose interest in science. It is for this reason that we have decided to concentrate mainly on the 9-14 age group.

In contrast to our rather tight focus, two influential and more recent reports concerning ICT in education are scoped much more broadly. For example, BECTA's (2005) review of the progress of ICT in education confines itself neither to particular curriculum areas, nor age groups, but considers education across the board, encompassing the post 16 and adult education sectors, as well as primary and secondary schools. BECTA report significant levels of improvement in the extent and effectiveness of ICT usage in teaching and learning across the education system as a whole. However, there remains

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[3] http://www.ost.gov.uk/enterprise/dtiwhite/

a great deal of variation in schools provision, both between primary and secondary schools (on the whole secondary schools are better provided for), and also within these sectors. A significant minority of schools still has what is considered to be poor access to ICT. Incidence of the use of computers in subject learning (as opposed to separate 'IT lessons') rises with the rising age of the pupils, though children of all ages are still likely to spend more time using computers at home than at school. ICT is judged to be 'fully embedded' in only 10-16% of schools, though 76% of the remainder are 'making progress' in this respect. BECTA call for a unified strategy for ICT in education, and increased understanding of ICT pedagogies and how to support them. This is important because it is in this educational and technological context that current eScience activities are taking place.

The DfES (2005) e-Strategy document *Harnessing Technology: Transforming Learning and Children's Services* similarly covers all sectors of education (including Further Education (FE), Higher Education (HE) and adult education), with the addition also of children's services. The remit of the DfES is to transform practice across these domains, by means of ICT. This document makes the important point that such a transformation involves a great deal more than simply providing additional money for hardware and software purchase; it implies institutional (and curriculum) change. Such change should not be allowed to proceed haphazardly, driven merely by new technological possibilities and available funding to pay for them, but requires careful consideration, wide consultation and meticulous planning. In view of this, we have attempted to position our own review *vis-à -vis* these important studies. Other notable resources from which we have drawn are recent reviews funded by Nesta, particularly those of the use of ICT in science education at primary (Murphy 2003) and at secondary level (Osborne and Hennessy 2003).

AIMS

The aims of this review report are thus fourfold. We aim to discuss and define e-Science in the context of education; to review the relevant literature in psychology, education and computer science; to present UK case studies of e-Science in education; and finally to present some possible benefits and limitations of e-Science in schools.

1.2 MODELS OF SCIENCE EDUCATION

Given the prominence of debates about, for example, how best to teach children to read, it is perhaps unsurprising that there is also no real consensus among experts on other important educational questions, such as what constitutes an adequate science education. However, it is probably true to say that far less media attention and public discussion has focused upon the science curriculum than on questions related to literacy and numeracy, around which there have been a number of moral panics over the last few years. In comparison, there seems to be something of a lack of attention to (and awareness of) the content of science education, despite concerns over students' apparent disinterest.

This was reflected in the rather uncritical adoption in the National Curriculum, of one model to the exclusion of others. Osborne and Hennessy (2003) and others have provided a useful outline of the history of science education, and we do not intend to repeat this here. However, it is necessary to give at least a little thought to issues of historical context. Science education has its early roots in 19th century realisations that the continuing transformation from a largely agrarian to an industrial society would require a scientifically and technologically skilled workforce (Osborne and Hennessy 2003). Nineteenth century calls for the initial establishment of science education were expressed in terms not unlike the recent calls for its improvement, for example in the White Paper of 2000. One stated purpose now, as then, is to help secure the UK's competitiveness.

The question implicit here, is how best to achieve this goal. Should we think about science education as a form of early training for the next generation of scientists, or alternatively, as a means to achieve a scientifically literate public capable of participating in informed debate about the social, economic, legal and ethical issues raised by emerging technologies? It is, of course, not necessarily a question of one or the other; it could be that both are required. The idea of 'scientific literacy' itself has not gone unchallenged. Bybee (1997) showed how the term has been used variously as a slogan, a definition and a metaphor, and suggested a framework to identify degrees of scientific literacy. Within this framework, an individual may exhibit several levels of 'literacy' at once, depending on the context, the issue and the topic concerned. This indicates that there is unlikely to be one, overarching 'scientific literacy' which can be achieved by the implementation of certain teaching methods. However, problematic as this concept may prove to be, we will follow Murphy (2003:8), in taking scientific literacy, for the purposes of this report, to refer to 'the minimal scientific knowledge and skills required to access whatever scientific information and knowledge is desired.' In a society where science and technology form an important part of our culture, clearly this is not a trivial issue. All of this suggests that there is no one, clearcut goal of science education, but a number of subtly different ones.

The first and (up to now), dominant model of science education is based upon the idea of providing a pre-vocational foundation for future scientists. For example, in the English and Welsh National Curriculum, fundamental concepts in physics, chemistry and biology are laid out as a list of separate items of knowledge. This model has attracted criticism from a number of standpoints. For example, Coles (1998) suggested that a knowledge of science is only one component among the many needed to enable a person to work effectively in scientific or technological occupations; other attributes, such as a willingness to collaborate with others, communication skills, and the ability to think analytically, are equally important. Furthermore, the scientific knowledge that *is* required, is likely to be very specific to the context in which the work takes place. Millar and Osborne (1998) use an architectural metaphor to criticise the over-concentration on the detailed content of science (the 'bricks') which, they say, may prevent students from ever coming to appreciate the huge significance of ideas such as Darwin's theory of natural selection, or Dalton's of atoms (the 'cathedral'). More fundamentally, since only a minority of children will enter scientific careers, there seems scant justification for insisting that all should undergo the basic training, when other approaches might be much more useful in terms of, for example, equipping people to engage with topical scientific debates (Osborne and Hennessy 2003). Hacker and Rowe (1997) and Wadsworth (2000) have argued that the system of testing associated with the National Curriculum has undermined opportunities to discuss and engage with interesting ideas raised by parts of the curriculum because teachers feel impelled to concentrate upon the purely factual information that is assessed in the tests. This has been implicated as a partial explanation for children's loss of enjoyment of science, as constructivist theories of teaching science are over-ridden at this stage by the necessity to do well in the compulsory tests (Murphy 2003). Harlen et al (1995) have identified problems with some primary teachers' lack of scientific knowledge, and, linked to this, the level of the content of the primary science curriculum has been criticised as too difficult (Murphy, Beggs et al 2001). Finally, Donnelly (1999) has highlighted the problematic nature of the practical elements of the curriculum, since they are based upon a simplistic, restrictive and limited view of scientific practice, and thus are not capable of reflecting either what scientists actually do, or explaining the power of science.

The second model on the other hand, rather than concentrating upon the conveying of a body of scientific fact, relies more upon providing an understanding of scientific practice, and scientific thinking. This model is informed by the work of historians, philosophers and sociologists of science over the last 40 years, which has debunked, among other things, the idea that there is a single 'scientific method'. On the contrary, it has been shown that different sciences in fact use different methods because they have different aims. Though it is true to say that the hypothetico-deductive method (often enshrined as 'the' scientific method) dominates in sciences such as physics, whose aim is to develop explanatory models of the physical world, this is not the case with all sciences. For example, in evolutionary biology and similar sciences, the aim is to establish a reliable historical record rather than to construct explanations (Osborne and Hennessy 2003).

This body of work sees science as a cultural product, much like other institutions and practices. For example, Kuhn (1962) argued against the conventional view of science as a steady, cumulative process of knowledge acquisition over time. Instead, most scientists, for most of the time, engage in what Kuhn termed 'normal science', which is carried out within 'paradigms', or collections of accepted beliefs about how scientific problems should be approached and understood. According to Kuhn, paradigms are essential to scientific inquiry, providing a framework to guide the research efforts of scientific communities. Periodically, a paradigm shift occurs, driven by the accumulation of results that contradict the dominant paradigm, which eventually become impossible to ignore. A science thus develops through a pattern of successive transitions from one paradigm to another through a process of revolution. Science is thus not simply the impartial study of the natural world, but like other human activities, involves sets of actors embedded in social networks governed by implicit and explicit rules and codes, and competing for prestige and funding. Kuhn's work has been influential, leading sociologists and others to study scientific contexts in much the same way as other social contexts have been investigated. Some well known examples of this type of work can be found in Barnes et al (1996), Collins and Pinch (1993), Latour and Woolgar (1986), and Pickering (1984). This view of science was (and is) controversial; an extreme position is that scientific knowledge is socially constructed, rather than being objectively determined. This led to the backlash of the so-called ‘Science Wars’ in the 1990s, a series of acrimonious clashes between some of the proponents of these views, and groups of natural scientists and others who opposed them.

There is now however a general (albeit still sometimes rather uneasy) recognition that science has social aspects, which is not at all the same as accepting the suggestion that science can be reduced to a mere social construct. These social aspects are particularly salient in respect of emerging science. This is important because most of the public debate thrown up by modern science is due to uncertainties about new scientific knowledge. Topical examples include debates about genetically modified (GM) foods, the effects of mobile phone technology on human health, and stem cell research. It is argued that an appreciation of ‘science as culture’, rather than a detailed knowledge of the actual technologies concerned, which constitute fast-moving fields which are subject to constant change, equips people better to participate in these debates. Steve Fuller (1997), for example, suggested that most of what non-scientists need to know in order to make informed judgements about science falls under the auspices of history, philosophy and sociology of science (the discipline known as science and technology studies, (or STS), or Sociology of Scientific Knowledge (SSK) rather than actual technical scientific content. It is after all straightforward to find up to date information on these aspects, for example on the internet, if required. However, school science has until recently barely acknowledged this aspect, which undeniably offers an alternative view of the aims and functions of science education.

1.3 LEARNING IN SCIENCE: CONSTRUCTIVISM, SOCIAL CONSTRUCTIVISM AND REFLECTIVE PRACTICE

Just as there are different models of science education, so too are there different ideas about how we learn. In order to improve learning, or change the ways in which we learn, it is necessary to think carefully about what learning is, and what it entails. One influential approach is that of constructivism – that human learning is actively ‘constructed; that is, learners build upon what they already know. Constructivism is based upon the theories of psychologists and educationists such as Piaget and Bruner, and places the child at the centre of the learning process – hence, ‘child centred education’. Jean Piaget (1896-1980) originally trained as a zoologist, and this influence permeates Piagetian (and neo-Piagetian) theory. He saw intellectual development and learning in evolutionary terms. Just as any organism must try to adapt to its environment, so a learner actively tries to make sense of the world.

A child progresses through distinct (though often overlapping) stages of intellectual development, just as she would earlier have passed through a series of stages of embryonic development *in utero*. Learning at each stage occurs by processes of assimilation – relating new information to existing knowledge structures (which are initially rudimentary in the infant, consisting mainly of inborn reflexes, but become increasingly complex over time); and accommodation, where old structures develop over time into new ones, as newly acquired information proves overwhelmingly contradictory, or otherwise cannot be successfully integrated into the old structures. These processes of assimilation and accommodation are held together and controlled by the force of 'equilibration' which can be seen as a force of balance and stability. To carry the biological metaphor further, equilibration can be compared to processes of homeostasis, which regulate the internal environment in higher animals. One example is the temperature control mechanism in homeothermic animals (including ourselves), by which the internal body temperature is maintained within narrow limits. Learning does not cease once adulthood is attained, but continues throughout life. A full account can be found in Piaget (1983), and important discussions of this theory in Vuyk (1981), Gelman and Baillargeon (1983), and Beilin (1992).

Murphy (2003) called attention also to the usefulness of information processing theories of learning to understanding constructivism. Instead of a biological metaphor, information-processing models of learning take a computational one, focusing on the mental processes that deal with information, how they are organised, and how they change during learning or development. There are a number of similarities with Piagetian ideas, such as a focus on the mind or brain of the individual, and an assumption that psychological structures or processes control people's behaviour more or less independently of external influences such as the individual's social environment or culture. Some investigators, notably Case (1984, 1985) have proposed neo-Piagetian models of cognitive development, which use information-processing terminology. There are a number of information processing theories (or more correctly perhaps sets of approaches), but the one most usefully linked with constructivist learning includes such variants as 'parallel distributed processing', 'neural networks' and 'connectionism'. Such approaches are compatible with what we know about how the nervous system works. Some well known proponents are McClelland and Rumelhart (1986), Minsky (1988) and Clark (1989).

What is proposed varies somewhat according to the precise model under discussion, but a basic principle is that information processing involves a large number of units working together in parallel, with units (like neurons) stimulating or inhibiting each other through networks of connections. These units process very small pieces of information (far smaller than meaningful symbols), and information is not held to be stored in a localised place (such as a long-term memory) but exists only as a pattern of excitation and inhibition between units. Connectionist networks can learn from experience by changing the weights or strengths of the links between the units; units that are active together have their excitatory connections strengthened and their inhibitory connections weakened and vice versa. This model can provide a reasonable explanation for the sort of gradual learning over time that occurs when we learn a language, or when a small child learns to speak for the first time.

These theories contribute towards an understanding of 'cognitive constructionism', which can be taken to refer to the learning of an individual child as she constructs meaning based on her experiences (Murphy 2003). Proponents of *social* constructivism however, stress also the importance of the learner's environment, and social interactions (Le Cornu et al 2003). This approach is based on the work of Vygotsky (1896 -1934). Vygotsky died leaving much of his work unfinished, and his ideas have been developed, often with some degree of disagreement, by followers such as Kozulin (1986) and Zinchenko (1985). It is also the case that Vygotsky's work has been translated from Russian to English only comparatively recently. Since elements of any language are difficult to translate directly into another, translation inevitably implies some degree of interpretation, and criticisms have been made of the accuracy of Vygotskian interpretations (Sutton 1983). Contemporary Vygotskian theory may also incorporate some of the insights of Hegel, Mead and others (Meadows 2004). For these reasons, this too, should be seen as a set of approaches rather than one unified body of work (Meadows 2004).

Vygotskian or neo-Vygotskian models differ sharply from the others in that an acculturation or apprenticeship model is implied. Learning is seen as an inherently social activity, rather than something that goes on purely in the brain or mind of the individual. In Vygotsky's terms, '*…Any function in a child's cultural development appears twice, or on two planes. First it appears on the social plane, and then on the psychological plane. First it appears between people as an interpsychological category, and then within the child as an intrapsychological category'* (translated by Wertsch 1981). According to these theories, people learn from interacting with other people, be they teachers, parents or peers. Their knowledge can therefore be said to be socially constructed. Learning takes place via processes of 'scaffolding'; to begin with, the adult (or more experienced peer) has to provide almost all of the cognition for an activity or task, but as the child becomes more familiar with it, she can take on more and more of it, until she can successfully complete it by herself. Repetition of this scaffolding on learning on related activities extends the child's competence, and she will eventually be able to perform new examples unaided. In this way, the child is supported by an adult or more experienced peer in the 'guided reinvention' (Meadows 2004: 166) of knowledge which previous generations have constructed. Vygotskian models stress the importance of semiotic systems such as language in this process, seeing these systems as a product of the history of a culture. A child is seen as passing through developmental stages, though for Vygotskian theorists, this is mainly seen in terms of language development. An important concept in relation to development is that of the 'zone of proximal development', or ZPD. Vygotsky (1978: 86) argues that, to provide useful learning opportuntities, we must consider at least two developmental levels; first, what the child can currently do independently (the usual educational test measures can determine this), and second what the child could do if she were provided with assistance in the form, for example, of demonstrations, prompts or leading questions. Identification of ZPD is therefore necessary not only to determine the child's current abilities, but also for the optimum targeting of instruction. Programmes of learning are thus best devised which are slightly in advance of her current abilities.

One criticism that can justifiably be made of social constructivist approaches is that devising individual programmes of learning in this way can seem an impossible task in a class of 30 or more children, each of whom may have a different ZPD. On the other hand, it can also be argued that the view of progression implicit in the National Curriculum, which assumes that all children learn in the same sequence (Cohen et al 1996), is overly simplistic, and incompatible with constructivist and social constructivist approaches. Analyses of constructivist, ‘hands on’ approaches to learning science, for example Keogh and Naylor (1996), have shown that children need help in order to make sense of practical activities by relating them to their previous experience. Left to themselves, they tend to spend insufficient time on both initially planning the activities, and interpreting their findings. Donald Schon’s (1983, 1987) concept of ‘reflective practice’ is poignant here. Schon’s, model builds upon previous work, such as that of John Dewey (1859-1952), and forms the basis for professional training in the fields, for example, of teaching and nursing. Schön argued that, when effective practitioners come up against a problem, they work instinctively; drawing on previous similar experiences, they rehearse various possible solutions until the issue is resolved. Schon termed this process ‘reflection-in-action’. Further, by evaluating and reflecting upon the event afterwards – ‘reflecting-on-action’, practitioners enhance their learning and add to their ‘repertoire’ of experiences, from which they can then draw in future problem situations. Schön believed that it was this ability to reflect both in, and on action, that identified effective practitioners from less effective ones. Some of the work featured in this report demonstrates that the use of technologies which provide opportunities for reflecting upon practical work undertaken in science has the potential to promote greater understanding of scientific concepts.

1.4 WHAT COUNTS AS ‘e-SCIENCE’ IN THE CONTEXT OF EDUCATION?

Just as there is lack of consensus about what counts as an appropriate science education, about teaching and learning methods, and about terminology such as ‘scientific literacy’, it is also the case that eScience has been defined in a variety of ways. Professor Sir John Taylor, Director General of the UK Research Councils, states that eScience is *“science increasingly done through distributed global collaborations enabled by the Internet, using very large data collections, terascale computing resources and high performance visualisation".* [4] Closely allied with the concept of eScience, is that of the computational grid. The idea is to provide a reliable, easy-to-access source of computing power and/or data on demand through the use of computer networks, corresponding to the way that the national electrical grid works to provide consumers with a reliable electricity supply.

This analogy itself has however raised questions. Anderson (2003) pointed out that the electrical grid implies centralisation (and thus the potential for central control, for example over access), and raises issues of inter-dependency. Recent problems experienced in power supply in areas of North America and Europe have led to calls for the grid to be replaced, or at least supplemented, by decentralised energy generation and supply options. Anderson warns that the idea of replicating a centralised, inter-dependent Grid at a point when the problems of such an approach are becoming clear, warrants early

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[4] http://www.rcuk.ac.uk/escience/archive/phase1.asp

consideration. She brings to our attention an alternative analogy: that of the world wide web. This implies a different model for the computational grid, perhaps moving more towards ideas of self adaptive systems, freedom of access and decentralization. This controversy, over a central concept, serves to demonstrate that eScience remains for the time being an exciting innovation based upon novel technologies, rather than an established institution. However, progress is likely to be rapid, and it promises huge potential for fields beyond large scale academic and commercial scientific research. In particular, it has the potential (as the JISC demonstrators and other projects featured in Chapter 3 indicate), to transform education, particularly in science.

Since there appears so far to be no clearly established definition of eScience in the context of education, it is necessary, in view of the need to scope this report, to give some consideration to this issue. A great deal has been published in respect of ICT in education (including specifically science education, for example Murphy (2003) and Osborne and Hennessy (2003), from which this report has already drawn. However, we consider that eScience is more specific than ICT use (or ICT integration) in science teaching and learning. Weller's (2002) account of 'online education' is also useful, in that he identifies a strong link between the pedagogy and the possibilities of the technology itself. He stresses that online education requires an entirely new approach, and is not simply a matter of putting learning materials on the web. He discusses the reasons why audio-visual technologies such as TV and radio broadcasts have failed to become the primary delivery method for distance education courses, and charts the unfulfilled promise of 'educational technology' such as CD Roms, which had initially been hailed as 'the new papyrus' (Lambert and Ropiequet 1986). Though all of these resources are widely used both in distance learning for adults and in schools, this use is very much as a supplement to more traditional teaching activities, rather than in any sense a replacement. The main focus of Weller's discussions of online education is on adult education. However, much of what he says about the uses of ICT in adult education is applicable to school contexts also. However, 'online education' in science is not the same as 'e-Science in education', although as we will see, e-Science activities as we understand them may indeed use technologies such as TV and the internet.

Recently, attention in education fields has focused on the educational potential of computer games and although games, like the other tools mentioned, do not by themselves constitute e-Science they too can play a significant part. For comprehensive accounts see Kirriemuir and McFarlane (2003), or McFarlane, Sparrowhawk and Heald (2002). This is an area in which there is currently expanding interest, with a number of projects underway. For example *Making Games*, jointly funded by the EPSRC /ESRC /DTI under the PACCIT LINK programme, led by David Buckingham of the Institute of Education, aims to develop software to enable young people to author computer games, thus constructing them as makers, as well as consumers, or computer games[5].

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[5] Details of the project can be found at http://www.lkl.ac.uk/research/pelletier.html.

Another potentially useful concept is that of ‘e-learning’. Coultas and colleagues at Sussex University are currently conducting a review of the effectiveness of e-learning in the post-16 sector. This work is funded by Eduserv[6]. The group has consulted widely about how e-learning should be defined, and have found that, as with eScience in education, there are a number of possible definitions. Some are very broad. For example, the Department for Education and Skills define e-learning thus: ‘If someone is learning in a way that uses information and communications technologies (ICTs), they are using e-learning’ (DfES 2003)[7]. In May 2004, the Reveel group held an initial expert seminar whose purpose was to define the term for the purposes of their review. The following definition was the result: ‘e-Learning is the capability required of learners/users in order that they can manage their own learning in the 21st century, using technology as appropriate to context, sector and task’ [8]

The Reveel team’s concern is with the 16-19 age group, and although many of these students are indeed capable of (and motivated to) ‘manage their own learning’, this might seem too much to ask of 9-14 year olds. However, a great deal of variation exists in the post-compulsory sector, which encompasses learners ranging from ‘A’ level students aiming for good university places, to school leavers with learning difficulties undertaking basic skills and pre-vocational courses. Technology use may of course benefit and motivate learning in both groups (and those in between), but there will be a great deal of variation in their capacity to ‘manage their own learning’, with some able to take on far more responsibility than others. The Reveel team use the careful proviso ‘as appropriate to context, sector and task’, which leads to a consideration at least, that ICT may also allow younger learners opportunities to take more responsibility for managing their learning, within a structured and supportive learning environment.

Murphy (2003), citing Ball (2003) identified four ways to use ICT in primary science. Firstly, ICT can be used as a tool, in the form for example, of spreadsheets, databases or dataloggers. Secondly, they can serve as a reference source, perhaps in the form of the internet, or educational CD Roms. Thirdly, they can be used as a means of communication, on a remote basis, as in email and online discussion groups, or for co-located communication, in the form of presentation technology such as Powerpoint and interactive whiteboards. Finally, they can be used as a means of exploration. Murphy (2003) gives the examples of devices such as the ‘Roamer’ and ‘Pixie’ robots that children can learn to programme, as well as various forms of simulators, and virtual reality. There is obvious overlap amongst these categories – many would consider for instance, that the use of sensors, as well as allowing the collection of data (considered by Ball (2003) and Murphy (2003) as an example of ICT as a ‘tool’), provide considerable opportunities for exploratory activities also. It should also be borne in mind that

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[6] See the project website at http://www.reveel.sussex.ac.uk

[7] http://www.dest.gov.au/NR/rdonlyres/96FC9E3C-BB50-47B3-89AF-D3054D14DA9A/1915/TowardsaUnifiedeLearningStrategy.pdf

[8] http://www.reveel.sussex.ac.uk/showpage.php?page=19.

any single science lesson or activity might use ICT in two or more of these ways. However, these categories have been useful in framing the definition that we adopt for the purposes of this report, for eScience in the context of education. We propose that educational eScience activities should use ICT for communication and collaboration purposes. Since eScience is in essence a tool to enable scientists to share and compute data at a distance, we envisage that this should include remote as well as co-located communication and collaboration, perhaps occurring between children in different schools, or groups of children from the same school, but in different locations, or groups of children and one or more adult facilitators. According to this working definition the use of Powerpoint by a group of children to present a science topic to co-located classmates would not, on its own, be e-Science (though this activity might of course form part of a wider e-Science project). We also envisage that the communication should be intended as a means for children to share and discuss scientific data or topics. Hence, we propose the following definition for e-Science in the context of education: 'The use of ICT in education, to enable local and remote communication and collaboration on scientific topics and with scientific data.'

1.5 BEYOND SCIENCE … AND BEYOND SCHOOLS

In this section, our task is to briefly consider three, linked issues that have arisen from our discussions so far. These issues, we think, are important. We acknowledge that there is insufficient time or space here to address them in depth. Therefore, our approach at this stage is very much that of opening them up for further research and discussion. Firstly, we consider the possibility of extending 'e-education' techniques to other curriculum areas in formal education settings. We raised the point earlier that science has important social aspects, and these aspects are likely to be shared with, or at least similar to, aspects of other fields of study. This in itself raises a number of interesting questions, such as whether these similarities can be capitalised upon in adapting novel teaching and learning strategies from science to other school subjects (or vice versa). Taking into account our definition of 'eScience in education' above, it could be that this is already beginning to happen, for example in subjects such as history.

BBC history's WW2 People's War project[9] invites people to add their own stories, photographs and so on of wartime life, or those of friends or family members, to a growing web-based archive. This seems an obvious way to engage older people in the use of ICT, but, given the prominence of the Second World War period in the history National Curriculum, it is unsurprising that there are also resources for schools on this site. There are lesson plans, classroom activities for primary, secondary and post-16 use, and links to other resources. One suggestion is that schools link up with older people in their communities, inviting them into the classroom to talk to students about their wartime experiences. Students then add the data to the archive (or assist the visitor to do so) under the supervision of a teacher or helper, and later carry out classroom activities based upon both the data they have collected, and other information gleaned from the website's archive and from other sources. Such activities can

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[9] http://www.bbc.co.uk/dna/ww2/

be scoped to cover the skill and content requirements for parts of the English, History, ICT and Citizenship curricula. This type of activity would fit into our specification in that the children would be remotely collaborating widely with others using ICT (in this case the internet), by adding their own data to the archive for others to use, and in turn accessing and using others' data from the website in their further investigations. At the same time, they would of course also be collaborating on a co-located basis in school, both amongst themselves and with members of the wider community.

A second issue relates to how e-Science activities might be able to contribute to 'informal learning', which takes place outside of school. We mentioned the term 'formal education' above, and take it here to mean education that takes place according to organised curricula in schools, colleges and universities. However, this is not clear cut, and this can be illustrated by any number of scenarios. For example, does a class visit to a science museum count as a 'formal' or an 'informal' learning activity? As Hawkey (2004 p.13) pointed out, it is in reality too simplistic to label learning 'formal' or 'informal', and the increased use of digital technologies by, for example museums, science centres and galleries, may be making such distinctions increasingly unclear. What if, on their return to school, members of this class should access the science museum's website as part of a follow-up activity? It would probably be assumed that, as the site was accessed as part of a classroom session, this constitutes a 'formal' learning activity. However, if one of these children, engaged by this activity, should then access the website again at home after the school day had ended, perhaps wishing to find out more about a particular topic, or to share with a parent or sibling some of the information that she had found earlier, is this still 'formal' or does this same activity then become 'informal' learning? The formal / informal dichotomy is particularly problematic in respect of children and young people who are for some reason outside of traditional learning institutions. Technology has the potential to bring about a more inclusive approach to education for this group. For example, Ultralab's Notschool.net project[10] offers this group a virtual on-line learning community of learners, teachers and experts who share some innovative learning tools.

As well as museums, science centres and other facilities (and their websites), there are increasing numbers of other resources that can be accessed either inside or outside of the classroom, by both students and members of the wider community. The success of the recent BBC Springwatch programme, featured as one of our case studies in Chapter 3, which combined primetime TV wildlife programmes with an interactive website, is a case in point. In our estimation, and according to our criteria, Springwatch counts as an e-Science activity. From another perspective, it was also phenomenally successful 'reality' TV, whose viewing figures eclipsed those of other popular reality genre programmes such as Big Brother and Celebrity Love Island. Blake Morrison, writing in The Guardian of 16 June 2005, reported that Springwatch's viewers tended to be of a different age range from those who watched the other two programmes, pointing to the interest and involvement of an older demographic, and we take up this point below. However, there were also huge numbers of

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[10] http://www.notschool.net/ns/template.php

younger participants, as demonstrated by the numbers of schools taking part. Other online resources which offer science information, interactive games and other resources for teachers, students and parents include the 24 hour Museum's *Show Me* website[11], and Planet Science[12].

Finally, eScience has huge potential for engaging the wider community in scientific inquiry and debate. This is just one of a number of issues which needs further research. Just as school e-Science has the potential to contribute to the teaching of the skills necessary to participate in public debate on scientific issues, so the broader availability of eScience activities promises to engage sections of the population outside of the classroom, lecture hall or teaching lab situation, in consideration and discussion of scientific problems. For Springwatch, the underlying topic was that of global warming. It is not difficult to see how such strategies could be adapted or applied to other important scientific issues and problems. Wilsdon and Willis (2004) identified a need for 'upstream' public engagement in science. This means that engagement should take the form of involvement and dialogue early on in the development of new technologies, and not merely presenting them as a *fait accompli* which then requires 'public understanding' initiatives in order to facilitate their acceptance. Recently, and particularly since the unfolding of recent controversies such as those surrounding genetically modified (GM) foods, and the MMR vaccine in the UK, drives towards upstream engagement have accelerated. What is still not clear however, is exactly how public engagement should be accomplished (Wilsdon and Willis 2004; Diamond and Woodgate 2005). It is likely that a number of approaches are required. eScience represents one strategy by which individuals in the wider community, outside of the sorts of organisations and pressure groups which tend to be involved in official consultations, can become engaged.

1.6 SUMMARY

In this first chapter, we have listed the aims of this review, and opened up for discussion a number of issues and concepts that we consider to be important in relation to science education generally, and eScience in particular. We have identified two contrasting (though not necessarily opposing) models of science education. We have reflected upon research in relation to how people learn. We have asked the question 'What counts as eScience in the context of education?', and provided a tentative definition. Finally, we have considered the potential of eScience methodologies more broadly; for other curriculum subjects, and for science education and science engagement and participation beyond formal education institutions.

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[11] http://www.show.me.uk

[12] www.planet-science.com

CHAPTER 2 TOWARDS EDUCATIONAL eSCIENCE

2.1 INTRODUCTION

In this chapter, we review a range of international and UK based projects, in order to provide an overview of pockets of work currently being carried out. These projects do not all strictly fit our definition but they nevertheless have interesting implications for the field. Where possible, we point the reader to sources of further information, which may be academic journals, websites or other sources. However, this is not a literature review in the accepted academic sense. Since educational eScience is a new concept, conventional research methods such as searches of academic databases (such as the British Education Index and the ACM digital library), have generated comparatively little of relevance. Even general Internet search engines have yielded little. For example, although about 90,000 'results' were produced from a search on Google performed on 21 July 2005, for 'eScience in education', the only relevant findings related to recent JISC activities and the JISC pilots which are featured as case studies in Chapter 3. We have therefore been creative and proactive in our quest for relevant projects, relying mainly upon those we have come across in our own current and previous research in the area, and those revealed through networking and personal communications.

Another proviso is that we are keen to avoid duplicating existing work. For example, we have already comprehensively cited the Literature Reviews commissioned by NESTA, on Primary Science and ICT (Murphy 2003), and Science Education and ICT (Osborne and Hennessy 2003), which concentrates upon the secondary school sector. There are currently 11 other reviews in this series, virtually all of which have some bearing, we feel, upon our topic. Of particular importance are the reviews by Naismith et al (2005) on mobile technologies and learning, O'Malley and Stanton Fraser (2005) on learning with tangible technologies, Hawkey (2004) on learning with digital technologies in museums, science centres and galleries, and Sefton-Green (2004) informal learning with technologies outside school.

Also worthy of a mention here, is the GRID (GRowing Interest in the Development of teaching science) project, which is funded by the European Commission within the Socrates Programme. A European multidisciplinary consortium consisting of seven members is involved, and the project is coordinated by the Pôle Universitaire Europèen de Nancy-Metz in France. The UK partner is the School of Informatics at the University of Bradford. The aim is to create a network for the exchange of best practice in science teaching. This project may well produce new ideas and insights highly relevant to educational e-Science, and equally, some of the projects outlined in this review may offer potentially valuable contributions to the GRID project objectives. Full information on the GRID project can be found on the project website.[13]

For reasons of convenience, we divide the remainder of this Chapter into three further subsections. In subsection 2.2, we discuss some international eScience projects. Although the focus of this review is UK educational eScience, we feel it vital to include these excellent examples, which are well established, large in scale and involve numerous schools and learners. The ways in which they have been developed, and perhaps more importantly, been extended to make the opportunities available to large numbers of schools, may provide valuable insights for the next stages of implementation in the UK. Subsections 2.3 and 2.4 review some international and UK science education projects respectively, which, although they do not fall within our definition of educational eScience, are not only interesting in their own right, but, we feel, also have the potential to inform future work.

2.2 INTERNATIONAL EDUCATIONAL eSCIENCE PROJECTS

The United States has a number of well-established projects operated and funded through large consortia which include state agencies, universities and industrial partners, working alongside schools to carry out science projects over distributed networks[14]. We summarise some of these projects below.

CoVis, Collaboratories and their Descendents[15]

It is fitting that this series of projects should be mentioned first, since they were in many ways the precursors of educational eScience activities as we now define them. The CoVis, (Learning through Collaborative Visualization) Project was launched in 1992 by Roy Pea and his colleagues, based at that time at Northwestern University in the United States, in collaboration with a number of academic and industrial partners, and with funding from the National Science Foundation (NSF). The work of this

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[13] http://www.amitie.it/grid.

[14] Please note children in the United States start school at 5 years of age. Primary education encompasses grades K (kindergarten), and 1-5 (ages approximately 5-11). Secondary education encompasses grades 6-12. However, the terminology varies, as the US education system is very diverse. For example, grades 9-12 (approximate student ages 15-17) are often referred to as ‘high school’.

[15] http://www.covis.northwestern.edu

team sought to move beyond the emphasis prevalent at that time within much of the computer-assisted learning community, on the learner as an individual, and learning as a purely cognitive activity.

CoVis was an ‘educational networking testbed’ which aimed to facilitate new forms of science education mainly for junior high and high school students, by replacing the traditional, teacher-led, formally organised classroom, with a model where learners are immersed in ‘virtual learning environments’; distributed communities of scientists, teachers and peers whose interactions are facilitated by the internet and other digital technologies (Edelson, Pea and Gomez 1995). Harnessing these technologies, the CoVis team wished to challenge the idea that education is something that takes place solely in schools, shifting towards participative learning models that had existed prior to formal schooling (and still exist, though largely outside of it), such as apprenticeships, long-term mentoring and group collaboration. Such approaches more closely mirror the ways in which ‘real’ scientists work and train.

Students and teachers were provided with specially adapted versions of the scientific visualization tools used by environmental and earth scientists, along with communication and collaboration tools such as video conferencing and email, all accessed from desktop computers in the classroom, to provide a ‘collaboratory’ environment (Lederberg and Uncapher 1989). The characteristics of scientific visualizations have been described elsewhere (see Gordin, Polman and Pea 1994), but briefly, they utilise colour, form and motion to represent large, complex data sets in a dynamic way, allowing viewers to more easily observe the underlying patterns and processes. These techniques had already revolutionized some fields of science, and the team hypothesized that the advantages they held for scientists would hold for students of science too. Such techniques also offered the possibility of opening up new domains of science to school students, that were previously considered too complex because of their reliance on formulae and abstract representations.

The scientific visualization tools required considerable modification for classroom use. They had after all been developed for use by experts. Adaptation involved the creation by CoVis researchers of ‘front-ends’ to scaffold use by novices. The team developed a procedure consisting of a number of steps in order to do this (Edelson et al 1995). Firstly, observations were made, of the use of the visualization tools and data sets by scientists, to discover how they were used, and explore the types of questions they can be used to investigate. By observing, the researchers sought to articulate the tacit knowledge used in these scientific processes. Tacit knowledge is that knowledge possessed by a community (scientific or otherwise), which is typically not articulated in their practice, perhaps because practitioners have forgotten its importance, or they do not realise that they have it. This sounds complicated, and is. Think of having to describe to a visitor from another planet, all the steps required to make a cup of tea. Each step (First fill the kettle with water … What is a kettle? What is water? How full does it have to be exactly when you are just told to ‘fill’ something?) requires copious explanation, and raises new questions[16]. The sort of tacit knowledge the CoVis team identified included basic scientific principles, understanding of the limitations of data collection processes and the models used to enhance the data, and how to use the tools. This tacit knowledge was then made explicit in the structure of the software interface, and in the associated pedagogical activities, to enable the students to form meaningful questions. Finally, the visualization tools were evaluated and refined.

Using these techniques, the CoVis team developed visualization environments suitable for classroom use to cover three aspects of atmospheric science; the Weather Visualizer which provided short term localised weather data (Fishman and Damico 1994), the Climate Visualizer, providing similar data, but over a longer period and a wider area (Gordin and Pea 1995), and the Greenhouse Effect Visualizer (Gordin, Edelson and Pea 1995). Each was built on top of a scientific visualization tool already in use by scientists, and aimed to provide a structured and supportive user interface for learners. Students and teachers were now able to undertake project work on such topics as global climate change, soil science, land use, water quality and weather prediction using these visualization tools, and by using the communication tools that were also provided, collaborate remotely (as well as co-locatedly, within the classroom) with other students, teachers and scientists.

According to Pea (2002), a number of converging trends led him to the idea of virtual learning communities. Firstly, the movement towards more socially situated conceptions of learning, and the idea of intelligence (or cognition) as a distributed achievement rather than something which occurs or exists in individual minds; secondly, the availability and rapid growth in the use of the internet; and thirdly, a rethinking of the role of the teacher. Pea's team worked with teachers to develop new curricula and new pedagogical approaches to science teaching to take advantage of the new resources. Although it preceded the present day interest in eScience and grid technologies, CoVis was an educational eScience project as we have defined it. The project ended in 1998, but its website remains, providing an archive of CoVis materials.[17] Of particular interest perhaps is a presentation by Gomez and Pea (1996) to the National Science Foundation, which describes perspectives on the evaluation of the Covis project. [18]

This work continues in the LeTus Center for Learning Technologies in Urban Schools[19] based at Northwestern and Michigan Universities, under the leadership of Louis Gomez. LeTus began in 1997

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[16] For more comprehensive discussions of tacit knowledge, please see Collins, H.M. (1992). *Changing Order: Replication and Induction in Scientific Practice.* Chicago and London: University of Chicago Press

[17] http:www.//covis.northwestern.edu/info/papers

[18] http://www.covis.northwestern.edu/info/papers/pdf/covis-evaluation.pdf

[19] http://www.letus.org

as a National Science Foundation-funded partnership among the Chicago and Detroit Public Schools, Northwestern University and the University of Michigan, to improve urban science education through innovative, hands-on, project-based curricula. LeTUS researchers and participating teachers have developed curriculum units on topics such as air quality, animal behaviour, biology, communicable diseases, earth science, environmental science, physics, water quality and weather, for grades 4 and above. There is a particular focus on professional development for teachers. Over 80 inner city schools currently use LeTUS science curricula.[20]

The WORLDWATCHER Global Visualization Environment for Science Education[21]

Worldwatcher is now known as the GEODE initiative. The project was initiated by Daniel Edelson and Roy Pea at Northwestern University, again with funding from NSF. It is based upon the ClimateWatcher software released in 1996 as part of the CoVis project, and aims to provide an accessible and supportive environment for students to explore, interpret and analyse scientific data about energy transfer through the earth-atmosphere system, and climate change (Pea 2002). Users can create dynamic colour visualizations of many data types, including their own data, which can be imported into the software in standard spreadsheet format. Datasets for global climate change are used alongside human and physical geography data sets to allow students to examine the causes and effects of climate change. Data sets and student-friendly visualization software are supported by a multimedia database of supporting educational materials. Also included is an online notebook feature that supports text, diagrams, multimedia and clickable links to open specific datasets. This can be used by teachers to design and deliver activities, and also by students, to create their own projects and record their progress by annotating their visualizations. Middle and high school curricula are available for Worldwatcher via LetUs. Pea is currently investigating the potential of wireless internet learning devices (WILDS).

A number of other projects have adopted the 'student-scientist' partnership model characteristic of CoVis, allowing school pupils to access scientists' data and tools in an effort to bridge what Pea (2002:6) called the 'science education-scientific practice gap'. These include the GLOBE and Forestwatch projects described below. GLOBE, though based in the United States, is available internationally to schools in 106 countries, including the UK.

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[20] Letus research papers are available at http://www/letus.org/papers.htm

[21] http://www.worldwatcher.northwestern.edu

GLOBE[22]

The GLOBE project is a worldwide, hands-on education and science programme for primary and secondary schools. GLOBE is led in the United States by a Federal inter-agency program supported by NASA, NSF and the U.S. State Department, in partnership with colleges and universities, state and local education authorities, and non-government organizations.

GLOBE enables school students to take scientifically valid measurements in fields such as the atmosphere, hydrology, soils, and land use, and report their data via the internet. They can also analyse their data using maps and graphs on the project's web site, and collaborate with scientists and other GLOBE students around the world. Training workshops and supporting materials are available for teachers, along with a HelpDesk facility. The idea is that both teachers and students benefit from support and contact with other teachers, students, and scientists internationally.

FORESTWATCH: Students and Scientists Working Together Determining the Health of New England Forests[23]

Forest Watch, based at the University of New Hampshire (UNH), is an educational outreach program that involves primary and secondary school students working together with scientists on the collection and processing of data on air pollution damage in tree populations. The program was established in 1991, and now includes 160 schools and study plots across New England. This extensive participation has enabled UNH to conduct a regional analysis of the condition of forests over an extended period of time. Student data are integrated with spectral data collected from samples sent to UNH, and tropospheric ozone data collected from state and Environmental Protection Agency (EPA) air quality monitoring sites throughout New England.

Participating schools select a permanent sampling plot in a pine stand and conduct various ecological and biophysical measurements using scientific protocols developed at UNH. Results to date show that students can collect valuable data from a scientific standpoint, and that the program is educationally beneficial; students learn science and mathematics, and at the same time carry out valuable research in their local area.

Each year, students participate in three types of activities:

1. Collecting field data on local forest stands, including species composition, tree size for one species (white pine, *Pinus strobus,* a known bio-indicator of low-level ozone pollution)

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[22] http://www.globe.gov

[23] www.forestwatch.sr.unh.edu

canopy closure and ground vegetation. Students also collect physical samples and send them to the university for spectral analysis not practicable in school laboratories.

2. School based laboratory analysis of foliage for signs of ozone damage.
3. Image processing, and analysis of Landsat Thematic Mapper data for the area around their school.

Each year, a compilation of Forest Watch results is published on the website. A wide range of supporting educational materials are available to teachers and students at participating schools, and training is available for both participating teachers, and those who would like to participate for the first time. Initial funding for the development and implementation of the program was provided to the University of New Hampshire through the Space Grant Program and NASA. NSF provided funding between 1994-8 for the further development of teachers' support materials, and for expansion of the program beyond New Hampshire and Maine. Forest Watch is currently funded by the New Hampshire Space Grant Consortium.

NASA Projects[24]

NASA's website outlines a variety of educational activities aimed at children of all ages, and teachers. Although not all of these activities come strictly within the e-Science remit, the projects in the following section have a relevant collaborative element:

Earth Crew[25]

The Earth Crew project enables teams, which may comprise students, teachers, family members or others, to participate in NASA activities by supporting 'educator astronauts', fully qualified members of NASA's astronaut corps who also have expertise in K-12 (ages 5-17) education. Participation is very open; teams can be based in the United States or elsewhere. The only requirement is that each team must have at least one 'sponsor' who may be a teacher, or a student of 13 years of age or over, who can send and receive email. On enrolling, the 'sponsor' is asked to grade a number of potential web activities in order of interest. These include games, virtual tours, 'ask the expert' and collaborations. Crew members can also participate in 'missions'. The most interesting for our purposes is Mission 2: 'Science Lab from Space'. Crew members are asked to suggest potential experiments and activities that educator astronauts could carry out aboard the Space Shuttle and International Space Station. An online form asks for a description of the experiment or activity, an explanation of its value for learning and

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[24] http://www.nasa.gov/home/index.html

[25] http://edspace.nasa.gov/earthcrew/ec_mail.html

suggestions on how the proposer or her classmates could participate in the experiment or activity. A 'Mission Toolbox' is provided to help frame suggestions, and a 'Crew Locker' with downloadable graphics, and printable items such as bookmarks and posters.

NASA Explorer Schools[26]

This is a collaboration between NASA and the US National Science Teachers Association (NSTA), primarily aimed at science teachers, rather than pupils directly. Schools apply online for an opportunity to partner with NASA in a program designed to enhance mathematics, science, and technology learning for educators, students, and families. Each spring, a three-year partnership is established between NASA and 50 new NASA Explorer School teams, consisting of teachers and education administrators, from diverse communities across the United States. There is an emphasis on schools in deprived areas, and those that serve predominantly ethnic minority communities.

NASA invites the selected teams to work with education specialists from NASA Centres in an effort to spark innovative science and mathematics teaching for students aged between about 9-14 years. Teams of educators participate in professional development workshops at NASA field centres, and benefit from an ongoing partnership. While partnered with NASA, Explorer School teams acquire new teaching resources and technology tools, aimed at providing students with exciting learning experiences in science, mathematics and technology, and raising awareness of potential careers opportunities in these fields.

NASA Quest Challenges[27]

NASA Quest Challenges are web-based interactive explorations designed to engage students in authentic science and engineering processes. Students work in teams to mirror career roles, and interact with NASA experts via Q&A, chats, interactive webcasts and posted feedback on the website. Materials are available for teachers.

2.3 INTERNATIONAL EDUCATIONAL SCIENCE PROJECTS

Our definition presupposes distributed collaboration. There are relatively few projects at present that carry out this form of collaboration (though some of those reviewed below are moving in this

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[26] http://explorerschools.nasa.gov/portal/site/nes/

[27] http://quest.arc.nasa.gov

direction). The examples mentioned below offer insights on teaching and learning, or technology use in science education, whose applicability to our topic is worthy of further investigation.

The first example concerns the work of Hay and colleagues (Hay and Barab 1998; Hay, Elliot and Kim 2002; Kim and Hay 2005), who have developed a modelling and visualization tool to aid inquiry based learning in undergraduate astronomy. The Virtual Solar System project (Hay and Barab 1998) aimed to present students with questions and problems of the type that cannot be answered by merely consulting textbooks. Appropriate aspects of the solar system were modelled using the project's software, and the resulted models tested and revised by the students until they behaved as required. Hay, Elliot and Kim (2002) wished to study the transition from the co-located collaborative work within the classroom that was originally afforded, to remote, asynchronous collaboration among distance learners. A course website provided a range of information resources, asynchronous collaboration tools, and communication facilities including a Professor Course Messaging System, and a group threaded discussion area. Their exploratory study showed however that, though the students could manage to use the software successfully, and collaborated effectively, the use of the asynchronous collaboration tools was limited to setting a time for more direct communication in the form of telephone calls between classmates to talk through problems while each was actively engaged with the software. It proved much more useful for both students to be simultaneously looking at the model they were building during their discussions, and the telephone supported this activity more efficiently.

Kim and Hay (2005) focused their attention on the longitudinal development of expertise, as learners engaged with the system. One pair of students was observed over the course of a semester, as they developed what was termed a 'cognitive partnership' with the software. Pre- and post-testing, and examination of their written work as the semester progressed, showed that the course was generally successful in achieving its aims, since both the students' astronomical knowledge and their general scientific inquiry skills improved as a result of studying the course. However, this success was qualified. Kim and Hay (2005) juxtaposed theories of expertise (Ericsson 1996; Glaser 1996; Winn and Snyder 1996) with distributed cognition theory (eg Salomon 1993) to argue against the assumption that learners engaging with digital inquiry tools will immediately and unproblematically have rich experiences as novice scientists. On the contrary, learners are faced with multiple challenges of understanding the tools and inquiry processes as well as the scientific content. This is an important issue that deserves further investigation, for our purposes particularly perhaps in respect of younger learners, and less able and /or committed ones than those who featured in this study.

'Thinking Tags', small, wearable, microprocessor driven Group Wear tags, were used by Resnick, Berg and Eisenberg (2000) to enable children to design their own scientific instruments. The team found that this type of activity had the potential to spark interest even in those children who usually disliked science and found it difficult. One feature of the tags is their ability to create a system of feedback, from which students may gain increased understanding. MacKinnon, Yoon and Andrews (2003) used tags pre-programmed to run a genetics simulation, to help non-science graduate students to understand the principles of dominance and recessiveness. In the simulation, each tag was pre-programmed with a specific genotype that was not initially known to the students. The only information that they were given was 'their' eye colour, which was either green (dominant) or red (recessive). Their task was to meet with other tags and observe the total probability and random selection of the eye colour of their potential 'virtual offspring'.

In the simulation, four lights, each lighting up green or red depending on the genotypes of both tags that are meeting, denotes the total probability of eye colour (phenotypes) for potential 'virtual offspring'. For instance, if a heterozygous green eyed tag met a homozygous red eyed tag, the total probability would show up as two green lights and two red lights. Then, to reveal the actual eye colour selection, the student would press a button on the tag to randomly select one of the lights to stay on, while the others were shut off. Students recorded the results of their meetings, and these data formed the basis of class discussion on dominant and recessive characteristics. MacKinnon et al (2003) argue that the simulation provided a concrete experience with the underlying rules for the processes of heredity, which could stimulate greater enjoyment, livelier discussions and deeper understanding of the topic than traditional pedagogical methods.

In a companion study, Andrews, MacKinnon and Yoon (2002) used the tags to help 5 year old kindergarten children to learn about the effects of sugar accumulation on their teeth. This is an interesting example, because it demonstrates that even very young children can potentially benefit from innovative methods in science education. Instead of just watching a demonstration of the accumulation of sugars on a screen, or being told about it, this simulation allowed children to actually experience improving or decaying dental health, but without real adverse effects. The simulation involved children participating in a game in which, wearing the tags, they pretended to 'feed' on a range of familiar food items placed around the room. These items contained other tags, which could emit information via infrared signals on the amount of sugar contained in a serving of that food. A time delay feature was added to simulate the relationship between accumulation and decay. After a specific time, which varied according to the amount of sugar accumulated (more sugar equals less time), healthy teeth (indicated by green lights on the tag) turned red, indicating a state of dental decay. Children then had 30 seconds to get to a brushing station before one of their teeth, or LED lights, turned red permanently, indicating the presence of a cavity. Children seemed to personally identify with the characteristics of their tag, and were observed collaborating with one another, urging classmates to brush their teeth when the lights on their tags turned red. Observations indicated that these young children were enabled by this game to understand the (difficult) concept of accumulation. When asked afterwards if they had learned anything from the activity, they commented that they had learned not to eat too much of the sugary foods.

2.4 UK EDUCATIONAL SCIENCE PROJECTS

Projects funded by the UK Research Councils

All of the UK research Councils fund public engagement activities, and many of these are school based. We present here a few examples from the wide range of Research Council funded activities. The application of Grid technologies could potentially enable far more schools to take part (and therefore more students to benefit) in these types of projects. Please see the individual Research Councils' websites for further information and examples of their work with schools.

The **Engineering and Physical Science Research Council** (EPSRC's)[28] Partnership for Public Engagement programme funds various projects for schools. The following three are of particular interest.

Introducing and Demonstrating Earthquake Engineering Research in Schools (IDEERS)[29]

Scientists at Bristol University's Earthquake Engineering Research Centre have developed a website to provide information on earthquakes and their effects. Students and others can find information about the causes and processes of earthquakes, how they affect people worldwide, and also what engineers can do to make buildings and other structures safer in earthquake zones. Linked to this is a competition to challenge 11-18 year old secondary school students to design and build small scale models of buildings that can stand up to earthquakes. The designs of individual students, or entire classes, can then be tested for different sizes of earthquakes on the Bristol lab's shaking table, which simulates the effects of earthquakes. For each design, scientists use the size of the earthquake that eventually destroys the model to calculate the efficiency ratio. The three models with the highest efficiency ratio in each session of the competition are the winners. The @Bristol science education centre[30], in collaboration with Bristol University ran its own version of the challenge in March 2005, for year 9 children in Bristol schools.

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[28] www.epsrc.ac.uk

[29] http://www.ideers.bris.ac.uk

[30] http://www.at-bristol.org.uk/

The Kitchen as Science Lab

The University of Cambridge is developing a range of experiments to allow children to transfer their scientific knowledge from school to their homes, so that it can be shared with their parents and other family members during the preparation of food. Each experiment will have a dedicated website to provide information appropriate to their stage of learning, from primary school to 'A' level. Information about the latest food imaging research being carried out at the Herchel Smith Laboratory for Medicinal Chemistry at Cambridge will also be available. The project aims to move science learning from the classroom to the home and community, and thus enable shared scientific experiences. eScience applications could enable the transfer of these kitchen science experiences back into the classroom once again, to allow comparison and discussion among students and teachers, and thus enhancing learning.

Controlling and Electron Microscope over the Web

This project, based at Manchester Materials Science Centre, is to be based on a website. Users, who may be school or college students, or members of the general public, can control a scanning electron microscope from a desktop computer, to view a range of specimens chosen to support the science National Curriculum and 'A' level syllabi. Users can control the magnification, focus and sample position of a chosen item. Others logged on to the site can 'look over the shoulder' and follow this exploration, or choose to view other images from an archive bank. The project's intention is to enhance learning by putting control in the hands of the user, thus enabling a much more active learning experience than is afforded by merely viewing images in a book or on a computer screen.

An example of schools work funded by the **Particle Physics and Astronomy Research Council** (PPARC)[31] is a 2004 award which contributed towards a series of visits to schools by Dr Aderin of University College London. Dr Aderin gave talks and demonstrations around the theme of a 'Tour of the Universe'. As well as the science learning opportunity provided by the talk and / or demonstration, pupils also had the opportunity to share her experiences of being a professional scientist.

Finally, The Biology and Biotechnology Research Council **(BBSRC)**[32] and the Natural Environment Research Council **(NERC)**[33] offer a Researchers in Residence scheme, which encourages PhD students to link with secondary schools and colleges.

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[31] www.pparc.ac.uk

[32] www.bbsrc.ac.uk

[33] www.nerc.ac.uk

Some other UK initiatives

Creative Partnerships[34]

Creative Partnerships is a national programme developed jointly by the Department for Culture, Media and Sport (DCMS) and the Department for Education and Skills (DfES), and managed by Arts Council England. Its aim is to develop the imagination and skills of young people through meaningful and sustained cultural and creative experiences in the formal and informal education sectors. Creative Partnerships currently works in 36 areas of England, with the involvement of a range of cultural practitioners, creative industries, businesses and local government bodies. Its aim is to move beyond what it calls the 'industrial' view of education as focused upon inputting facts and knowledge into children's minds, to allow children of all abilities to use their creativity to develop the confidence and imagination to be able to contribute to both the growing knowledge economy and an open and more diverse society. There have been a number of Creative Partnerships projects which have included science[35]. These have included CPD courses for teachers on the topic of creative science teaching, and in some instances have brought scientists, artists and others into the classroom to work with teachers and children. Some of these projects have included ICT, and some have an element of remote collaboration. For example, children in a Black Country primary school undertook a 'Virtual Journey' to Australia between November 2003 and March 2004, by means of communications from a teacher who was travelling in Australia at that time. This teacher sent pictures and information by text and email, which were used for class discussions, and as a basis for lessons across the curriculum, including science.

Teacher-Led Projects

Education, both as academic discipline and professional practice, has its own rich tradition of action research and reflective practice, and with this in mind, we are well advised to consider the research that teachers do on their own account, often small in scale and with little or no funding. Projects of this nature are often undertaken as part of teachers' continuing professional development (CPD) activities, and university-based educational eScience researchers would do well to monitor these small scale research activities. Much of this work, if it is published at all, is published as short articles in professional journals such as the UK's *Primary Science Review*, as opposed to high impact academic journals. One example, Earle (2004) describes how, during a primary science lesson which focused on predicting and describing patterns in data, a deep seated misunderstanding of the purpose, construction

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[34] www.creative-partnerships.com

[35] http://www.creative-partnerships.com/projects

and interpretation of line graphs was identified, even among the highest attaining children. Earle therefore devised a series of whole class lessons on graphs, using an interactive whiteboard.

Testing of the children before and after these lessons showed that the activity brought about a great improvement in the children's ability and confidence in the use of graphs. The interactive whiteboard allowed the whole class to see what was going on and to participate in the same way as a conventional whiteboard or chalkboard, but had the added advantage of allowing a much faster pace and increased interactivity, permitting the use of greater numbers of examples, simulations and other activities. Perhaps ironically, it was technology that had originally masked these children's misunderstanding; they had previously spent half a term drawing graphs using Microsoft Excel, and their fluency in the use of this software had hidden their misconceptions about axes and scales. Projects of this nature have the potential to offer insights not only into how ICTs can be used to enhance learning in the classroom, but also into the ways in which they fit, or do not fit, into established classroom organisation and practices. They can also show occasions where ICTs can inhibit learning, or at least mask lack of understanding, as was shown on this occasion.

Mixed Domain Projects

Some relevant projects are interdisciplinary in nature. That is, they concern not only science, but other curriculum areas as well. One example is the Ultralab SchoolNet Global project. Ultralab is the learning technology research centre at Anglia Polytechnic University. Much of Ultralab's work focuses on developing 'online learning communities'. Many of these are networks for education professionals. However, SchoolNet Global is available to teachers, students and families, and has science content. SchoolNet Global [36] is funded by DfES and commercial partners, and describes itself as 'the biggest children's contributory website in the world'. There is a focus upon international collaboration, intercultural understanding and promoting the study of modern foreign languages. Students in 34 countries have participated in a range of projects across the curriculum. School Net Global started in 1998 in the UK, as a collaboration between Ultralab and Intuitive Media. It is now available worldwide. Teachers, families and students aged between 5-18 can join. Students can write their own web pages, and work on a range of interdisciplinary projects, all of which place emphasis upon the global dimension. Teachers are encouraged to set up email links with partner schools in other countries. Of particular interest here are the following projects, which have science content:

i Animals Around Us,

This project is aimed at primary school students aged 7-11. It covers pet keeping, including learning how to look after animals, attitudes to pets across the world, and the different types of pets that are kept

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[36] www.schoolnetglobal.com

in different countries; issues of animal welfare, both at home and internationally; finding out about endangered animal species worldwide, and what can be done to prevent their becoming extinct.

ii Energy of the Future

Secondary students aged 11-14 consider the earth's energy resources in a local and global context, and address questions about renewable and non-renewable energy, energy consumption, and alternative energy sources. They can work with students at a school in another country to design a new energy source.

iii Global Weather Watch

This project is also for secondary students aged between 11-14. They study local weather patterns and global climate systems, and look at factors such as seasonal variations around the world. Students research and log weather data for different locations, and with students at a partner school in another country, can set up an international weather website, or run an international climate conference.

iv Mobile Phone Design

This project is aimed at 11-15 year old students, and focuses on mobile technologies. Students explore the ubiquity of mobile technologies, and consider their own and their families' uses of mobile phones. They can work with students at a partner school in another country to discuss questions of health concerns, patterns of usage, cost, function and design.

All projects include teachers' guides, with lesson plans, resources and National Curriculum links, examples of students' work and case studies from participating schools.

This chapter and the next should be viewed as a snapshot of the state of affairs as it stands in 2005, though space and time preclude the inclusion of *all* possible projects. Chapter 3, which follows below, presents a selection of UK based case studies of eScience in education.

CHAPTER 3 eSCIENCE AND EDUCATION CASE STUDIES

We have defined eScience in the context of education as: The use of ICT in education, to enable local and remote communication and collaboration on scientific topics and with scientific data. In this chapter we present UK case studies of educational applications of eScience in schools in line with this definition. All except for one involve or include students between 9-14 years of age, a crucial stage when it is considered that children are at most risk of losing interest and motivation in science. We summarise the projects highlighting the application of eScience technologies and the educational potential. Where the technology has been evaluated, we report the outcomes. There are few studies to draw from in this area as this work is still in its infancy. We report on these projects below and include their UK funders.

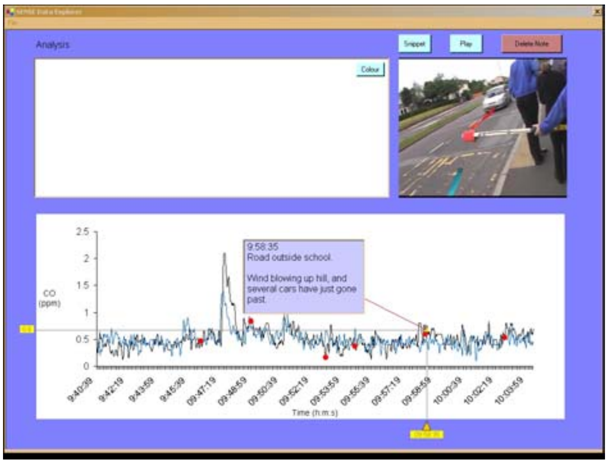
3.1 THE SENSE PROJECT: INTRODUCING eSCIENCE TO THE CLASSROOM

The SENSE project, funded by The Joint Information Systems Committee (JISC) of HEFCE, explored the potential of sensor technologies to support a hands-on approach to learning science in the school classroom (Stanton Fraser et al, 2005; Tallyn, Stanton Fraser et al., 2004). The aim of the project was to explore how emerging networking technologies could enhance science education, promoting a hands-on approach to learning science in schools. A particular emphasis was placed on understanding the scientific *process* and the use of video to aid in the understanding of context. The project aimed to support collaborative activity within schools, between different schools and with scientists.

Fig. 1. Hypothesising about pollution levels

Fig. 2. A group of children collecting sensor data

Taking the presence and impact of pollution as the area of inquiry, activities were carried out with children at two participating schools. The activities began with lessons based around hypothesising where pollution occurred by creating maps and counting traffic from webcams. Then some low-tech prototyping was carried out where children used cardboard and Vaseline to carry out a simple experiment, placing their low-tech 'sensors' in locations where they hypothesised high and low pollution and then examining the results. They were then ready to work with the technology and spent a number of sessions designing and using their own pollution sensors within their local environment. The technology consisted of a PDA and pollution sensor. The sensor was coloured differently on each side so that the direction in which the sensor was facing would be evident when children later inspected video data of the sensor in use. Children captured their own sensor data using this device. The data were downloaded to additional visualisation technologies to help them analyse their data and to understand it in the context of similar data. Children in Nottingham and Sussex then shared and compared their data, using an identical interface. Children also discussed their data with a pollution expert remotely.



9:58:35
Road outside school.

Wind blowing up hill, and several cars have just gone past.

Fig. 3.Data Analysis Tool Interface with CO graph, annotations and video context

Results of video analysis of the sessions and teacher interviews suggest that this context-inclusive approach is significant for three key reasons. Firstly, it allows individuals to reflect on method as part of data collection. Secondly it provides an aide-memoir to groups, who have collected data together, in interpreting results. Thirdly, it allows new participants who have engaged in similar processes to understand new perspectives on their own and others' data.

3.2 PUBLIC UNDERSTANDING FOR eSCIENCE

The Public Understanding for eScience project drew upon expertise and resources from the Equator IRC[37], and like SENSE, also involved young learners in collaboration over data on carbon monoxide (CO) pollution. The Public Understanding for eScience project however had a different aim; to give students and teachers an intensive eScience like experience, and reflect upon how the technologies involved might be used in schools. Secondary school students aged from 14-16, together with their teachers, used facilities at the University of Sussex to carry out activities including live communication with remote and distributed scientists, accessing and making contributions to remote research data, and using tools to make visualizations of their own data (Underwood et al 2004).

Five sessions were conducted with 43 selected students, who were in the top 10% of their year groups for science. Each session was run in two periods of one and a half hours. The first period took place in the lab. It focused on the Equator *Antarctic remote sensing project,* and involved interacting with remote experts and data. During the second period, participants concentrated upon Equator's *Urban CO monitoring project,* collecting CO readings outside with handheld sensors and location data with GPS devices. Visualizations of these data were generated using software and equipment from the *Urban CO monitoring project.* Participants were asked to reflect upon how the technologies used might be used to support learning in school. Analysis is still in progress. However, early indications are that, whilst all the participants enjoyed the sessions and found them valuable and engaging, teachers highlighted practical difficulties that would need to be addressed before such activities could be introduced into the classroom, including handling technology, finding researchers willing to participate, and finding research data relevant to the curriculum.

Fig. 4 CO monitor used in the Public Understanding for eScience project. With kind permission from Josh Underwood

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[37] www.equator.ac.uk

3.3 E-STAR FOR E=LEARNING – ACCESS TO PROFESSIONAL ASTRONOMY RESOURCES FOR SCHOOLS

The e-Star for e-Learning project, funded by JISC, ran from September 2003 to October 2004. The project was based at Liverpool John Moores University, and the aim was to use Grid technologies to combine and extend the features of two existing schools resources in astronomy. The National Schools Observatory (NSO) is a web-based system which allows schools to submit requests for access to a 2m telescope situated on the Canary Islands. These requests are placed in a queue, and typically there is a wait of a few weeks. The system also contains decision support tools to help teachers and students to choose what to observe, based upon their scientific and educational requirements, and a large quantity of supporting educational resources. The Faulkes Telescope (FT) is a programme providing live access for schools to two 2.0 m. telescopes based in Hawaii and Australia respectively, through a web browser during pre-arranged slots.

e-Star for e-Learning uses new Grid technologies developed by the original e-Star programme ('e-Science Telescopes for Astronomical Research') to combine the decision support elements of the NSO with the live access of the FT, and remove the need to pre-book slots. This allows teachers to spread out their observations, making them as they cover relevant aspects, instead of having to do all their observations in one or two sessions, with the associated possibility that poor weather could ruin a long-awaited experience for the students. As well as having the advantage of making the observations more immediately relevant to the students, less telescope time is wasted, and more schools can benefit. The project was trialled in a number of Merseyside primary and secondary schools, and Science Centres associated with Liverpool Museum and the university. Details are available on JISC's website[38].

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[38] http://www.jisc.ac.uk/index.cfm?name=project_estar

3.4 AMBIENT WOOD

This project, described as a ‘playful learning experience’ in the form of an augmented field trip in a Sussex woodland (Rogers et al 2004), ran during 2002 and 2003, and was funded by the UK Engineering and Physical Sciences Research Council (EPSRC) as part of the Equator IRC. Pairs of children, each pair equipped with a number of devices, explored and reflected upon a physical environment in which a WiFi network and RF location beacons had been placed. The aim was to encourage the children to reflect and learn when moving through and interacting with aspects of the environment. The children could communicate with a remote facilitator using walkie talkies, and were sent information via handheld PDAs. A range of devices and multi-modal displays were used to trigger and present this information. Delivery was sometimes triggered just by the children’s movements, and at other times by their intentional actions.

Fig 5 Children reviewing information collected in the woodland on PDAs. With permission from the Equator project.

The children explored the woodland during a 1 hour session, taking measurements of aspects such as light and moisture levels, and receiving multi-modal information using a variety of ‘pingers’. Their position in the woodland was constantly monitored using GPS and where the signal for this was poor, via a Dead Reckoning system. Children reported their experiences back to a ‘Den’ area, and the facilitator in the Den also sent them additional information, enabling them to make links between the organisms that they found. Afterwards, they reflected upon and discussed their experiences with the facilitator, in the Den area. They were also encouraged to hypothesize about what might happen in the wood in the long term under various conditions, such as drought. Back in the classroom, the same data were used to create food webs.

The study found that students were able to make links between what they encountered in the physical environment and the various types of digital information provided. Independent activity was encouraged, and student initiated modes of digital augmentation promoted reflection and discussion. Fears that children would not be able to physically manage the number of devices they had to carry proved to be groundless, since they shared the equipment and passed it between them as necessary. Potential problems of information overload were also managed successfully by the children, who simply ignored information on the PDAs when they were already involved with something else. It was concluded that digital augmentation promoted learning, and could be successfully extended to other types of spaces, such as museums. However, it was important to consider carefully which devices should be used, what additional information should be provided and how it should be delivered.

3.5 PHENOLOGY PROJECTS

Phenology is the study of the timing of recurring natural phenomena, especially in relation to climate. Though this study has its roots in the eighteenth century in the UK, and considerably earlier in other parts of the world, it has proved to be an ideal vehicle for modern day technology-enabled public participation projects. A UK national recorder network had originally been set up in 1875, but had ceased its annual reporting in 1948. A pilot scheme was set up by research biologists at the Centre for Ecology & Hydrology at Cambridge in 1998, to try to recreate a phenology network in the UK, that would be compatible with both historic records and international schemes. In autumn 2000, the Woodland Trust joined forces with the Centre for Ecology & Hydrology to promote phenology to a far wider audience. Over 21,000 people are currently actively involved with the UK Phenology Network[39], about half of them online. Of particular interest to schools are the linked Nature Detectives[40] and BBC Springwatch[41] (and Autumnwatch[42]) projects.

Nature Detectives, a scheme especially for children and young people, was set up by the Woodland Trust and the UK Phenology Network, with the help of Heritage Lottery funding. Its aim is to promote interest in the natural world among students between the ages of 4-18, and enable them to contribute to real scientific research about the impact of climate change. It is based on an online recording programme, and is widely promoted to teachers through INSET courses at Science Learning Centres around the UK. Also available on the website are downloadable curriculum-linked, printable material and interactive online quizzes, games and activities. Published print material for primary teachers is also now available (de Boo 2005, compiled in association with the ASE), and a secondary resource is planned for Autumn 2005.

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[39] http://www.phenology.org.uk/

[40] http://www.naturedetectives.org.uk/

[41] http://www.bbc.co.uk/nature/animals/wildbritain/springwatch/

[42] http://www.bbc.co.uk/nature/animals/wildbritain/autumnwatch/

Fig. 6 Bumblebee, one of the BBC Springwatch indicator species.
By Pete Holmes, with kind permission.

In Spring 1995, the **Springwatch** survey, the biggest ever survey into the arrival of spring, was launched by the BBC in association with the Woodland Trust and the UK Phenology Network. This provided a simple way to begin to contribute phenology data, and proved extremely popular, with over 157,000 contributions from schools, families and members of the public. Participants were asked to record the date of their first sightings of six indicator species, together with the grid reference or postcode of the location where the sighting took place. We include photographs of some of these indicator species here, with kind permission of the photographers and the UK Phenology Network. A species identification sheet was provided, along with other information, and teachers' resources. Data was input, and collated results viewable on web pages on the BBC website. Associated with the project, a popular series of BBC TV programmes showed the progress of selected species, such as breeding birds, through the season. The BBC **Autumnwatch** survey is currently underway.

Fig 7: Frogspawn another of the BBC Springwatch indicator species
By Margaret Barton, with kind permission.

3.6 ASE SCIENCE ACROSS THE WORLD[43]

Science Across the World is an international education programme developed and managed by the Association for Science Education (ASE) in partnership with GlaxoSmithKline. The programme is topic based, giving scope for exploring science issues which often differ from one region, culture or country to another. Science Across the World therefore necessarily goes beyond fact-finding; it explores science in its social context, and this makes for interesting exchanges of information, ideas and opinions between students in different countries (Cutler 2004). Teachers and students in 113 countries are currently involved. The value of this project has been widely recognised; it was a winner in the 2004 Global Best Awards for Education and Business Partnerships, and in the 2004 European Awards for Languages.

Lifetime membership is available to all primary and secondary schools at a small cost, and this enables them to set up exchanges with other schools throughout the world, and send Exchange Forms via the website in different formats. Schools initially choose a topic from the list on the project's website. Each topic includes teachers' notes, student pages and an Exchange Form. Students then work through the activities on the student pages, gathering ideas and data that they wish to share with other schools. The students then agree on the entries that they wish to make on a single Exchange Form. This often involves class discussions and presentations of the findings of individuals or small groups. Next, they select from the project's online database, schools that are working on the same topic, at the same time, and with similarly aged students. The Exchange Forms are then sent to the selected schools, and to any other schools who had asked to exchange with them. Once a number of Exchange Forms are received, students explore the different responses to the topic issues around the world, and discuss, display and report their findings.

Topics suited to children from age 8 to post-16 are available. A key aim is to help with the development of key skills, such as communication and working with others, and thinking skills. Topic activities can involve traditional 'practical' work, but in recognition that many schools in developing countries will have minimal specialist equipment, this is always designed so that schools in a wide range of situations can take part. All topics involve some form of active research however. For example, typical activities for 8-11 year old primary school students working on the 'Eating and Drinking' topic include surveying the food that they eat during a typical school day, investigating the labelling of foods in their kitchen cupboards at home, and the analysis of different advertisements for food. After the background research, activities always involve discussion and debate. As well as science skills, there is an emphasis on literacy and languages. Students may choose to communicate in

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[43] www.scienceacross.org

one or more languages. All topics are available in English, French, German, Italian, Portuguese and Spanish, and some are available in additional languages. In these cases, translations are often provided by enthusiastic teachers.

Fig. 8: South African students working on the What do You Eat? topic for Science Across the World in a Durban fruit and vegetable market. Reproduced with permission.

Most schools now use the project website to transfer their Exchange Forms, and this provides additional opportunities to integrate ICT into the curriculum. However, in recognition that this is not possible for some schools, it is also possible to exchange via post or fax.

3.7 WALKING WITH WOODLICE

This project was based on a British Natural History Museum Interactive Online Exhibitions Internet site, and ran from 2000-2004. Its key aim was to provide first hand experience for learners mainly within the 7-14 age group, to engage with real biological research. It also wished to explore the use of identification keys, and investigate the potential of the Internet as a means for sharing and distributing biodiversity data (Hawkey 2001, 2002).

Woodlice were chosen because they are common, widespread and well known, and it was relatively easy to develop a simple key to identify the commonest species. They are also safe, non-frightening, and not easily harmed by eager fingers. The project was launched as part of the British Association's 2000 creatingSPARKS science festival, with support from the ASE. Central to the project was the identification key, which is available in two formats. One has interactive links to further information and pictures, and the second is in a printable format, suitable for outdoor use. Background information is provided on biodiversity, taxonomy and systematics, and teachers materials with links to the English and Welsh National Curriculum are also provided. The activity fitted with the scientific enquiry part of the Science National Curriculum, and also aspects of the National Curriculum for ICT and mathematics. The website included a simple form for recording observations, which was submitted by email to the project coordinator. A measure of the project's popularity was that 2000 sets of data were received, mostly from schools, but some from individuals or families. Data were analysed and presented on the website as distribution maps, tables and graphs, and learners were asked to look for patterns, draw inferences and raise further questions. Expert data from an earlier survey (Harding and Sutton 1985) were displayed alongside the participants' data.

Fig. 9. Porcellio species woodlouse. Reproduced with permission from the Natural History Museum.

Fig. 10. Children in a wildlife garden. Reproduced with permission from the Natural History Museum.

The key concern of the project was with encouraging participants to submit their own data, and then to engage in analysis and comment, rather than with the validity and reliability of the data. However, the results were broadly as expected, and concur with expert opinion. The project is now completed (although the website remains to show archived material)[44]. The Natural History Museum are currently considering further developments.

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[44] http://www.nhm.ac.uk/woodlice/

3.8 e-MALARIA – DRUG DESIGN TOOLS FOR SCHOOLS

This project is funded jointly by JISC and EPSRC via the CombeChem e-Science Project, with help from the Cambridge Crystallographic Data Centre, who made their software (GOLD) available, and United Devices. It is the one project in this chapter that is aimed exclusively at learners outside of the 9-14 age group, in this instance ‘A’ level students (16-18 years). Although it is currently aligned with the A level syllabus, it is hoped that it can be used in the future for younger students also. The project is led by the e-Science group at the University of Southampton, School of Chemistry. This department has extensive research and funding links with the pharmaceutical industry. The aim of the e-Malaria project is to provide students with the opportunity to become involved with real scientific research, based on looking for potential new anti-malarial drugs. This is a genuinely urgent scientific problem, since over 1m people die annually from this disease, and problems of resistance to existing drugs, and the prospect of the disease spreading over a wider geographical range due to global warming, render the discovery and development of new drugs essential.

Fig. 11. Head of male Anopheles mosquito, by Christopher Curtis, London School of Hygiene and Tropical Medicine. Reproduced with permission.

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Students who attend Schools and Sixth Form Colleges in Hampshire are asked to design a compound which could potentially suppress the enzyme dihydrofolate reductase (DHFR). This enzyme is involved in the replication of DNA and is present in the malaria parasite and humans, but differing mechanisms means that the parasite is much more sensitive to blocking the DHFR enzyme than the human host. Therefore, it is possible that a new drug, informed by the compound, could have anti-malarial properties. The project is based on a website[45] which hosts a web-based browser to access software similar to that used by drug companies, but in an accessible manner and bringing together many elements of drug design. The site also provides information about the disease, and about the drug design process. Students use real drug design tools and are guided through the various stages of the

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[45] http://emalaria.soton.ac.uk

design process, from initial sketches of molecules to docking of the structure into the proposed active site to establish whether it is a good ‘fit’. They may also consult with other students and university researchers, and compare their progress with other schools through a group scoring table. The researchers leaders hope that involvement in a real chemistry project will promote understanding and interest in chemistry and science in general. The feedback so far has shown the site to be a very useful educational tool. It is hoped that the system can be maintained and extended in collaboration with the science learning centers.

CHAPTER 4 CONCLUSIONS AND FURTHER WORK

4.1 INTRODUCTION

Despite the on-going technical standards debates within eScience, the area is nonetheless one of existing genuine technical innovation. Projects across a wide range of scientific domains are already enabling access to large collections of remote scientific data and high performance visualisations of this data. As computer scientists make advances in determining how web and grid services will enable faster and more diverse access to data for professional scientists, there is a growing interest in potential uses of these technologies in the field of education, particularly in providing access to up-to-date and relevant information to children and teachers. The idea of combining eScience and education opens up exciting opportunities for widescale collaboration on scientific topics. Education is a domain which could benefit immensely from eScience technologies if appropriated correctly. The projects outlined in Chapter 3 begin to explore how to make these technologies available as an educational resource for schools. They represent attempts to give children a more global perspective by being able to share and compare their data with that of others and, although promising, these activities clearly require further development. In the following sections, we highlight some general points arising in our review. We note the possible direction indicated by current research, and describe the key UK research strengths which could be capitalised upon in order to achieve a more focused international contribution.

4.2 SUMMARY OF KEY ISSUES

A key objective of this review is to offer up for discussion a definition of eScience as it relates to education, and position this *vis à vis* debates about the nature of learning and alternative models of science education. Our intended audience therefore comprises not only fellow academic researchers, but also teachers, parents, education policy makers, funders and interested members of the public. This is important because science education should not be thought about in isolation from public engagement in science, or for that matter, from scientific practice.

eScience is potentially useful for increasing interest and motivation in science, and in providing additional opportunities to reflect upon what has been learned. However, it should not be seen as a complete solution to the problem of relatively low numbers of young people studying science beyond GCSE. In our reflections on models of science education and theories of learning, we noted a disjunction between the model within which the science National Curriculum is based and social constructivist learning theories. A number of other problems were also apparent; commentators have noted a lack of confidence and limited scientific knowledge in some non-specialist primary teachers, and pressure upon teachers to concentrate on the aspects upon which the compulsory national tests are based. This applies to the extent that students' interests are not followed up, and there is often insufficient time for class discussion. eScience methods and technologies cannot by themselves resolve these issues. Since moves to review the National Curriculum for science are underway, consideration should be given to the different purposes of science education. Perhaps the current model, which concentrates upon content of scientific knowledge, and represents a type of pre-professional training for would-be scientists, is not appropriate for all students. After all, not all children will take up scientific careers; however, all *will* be members of a society in which science and technology are important elements of our culture. All students should be provided with the tools to participate in public debates on scientific issues. In recognition therefore that science education has more than one purpose, increased flexibility and choice is necessary to avoid the current potential for students to exclude themselves from this important aspect of modern life, whilst at the same time providing motivation and encouragement for those who wish to pursue high level scientific study, and ultimately careers in science.

Our findings indicate that eScience has further potential beyond the classroom. We have seen that eScience, as with the Internet before it, tends to blur the boundaries between 'formal' and 'informal' education – formal education that takes place under the auspices of a school, college or university, and informal education that which takes place in everyday life. Informal education can take place at home, on field trips, in museums, zoos or science centres. These categories are not satisfactory; school trips to places of interest have for many years been commonplace, and many such establishments employ education officers who are qualified teachers, and can provide activities that link with the National Curriculum. Additionally children may visit with their school or class, and during the holidays and weekends, with parents and others. According to Hawkey (2004), museums and similar establishments do not wish to distinguish between 'formal' and 'informal' education. Finally, it must be recognised that not all students, for one or other reason, are able to attend school. Such students have little access to 'formal' education, and may become quite isolated. Networking technologies can enable them to join online learning communities, as demonstrated by Ultralab's NotSchool project.

Linked closely to the blurring of the boundaries between formal and informal education, is the issue of public engagement. This is seen as vital in respect of emerging technologies that pose social as well as scientific dilemmas (Wilsdon and Willis 2004; Diamond and Woodgate 2005). Pea (2002:6) argued that the 'science education-scientific practice gap' should be bridged, and that projects such as CoVis were capable of doing this. We would like to propose an addition to this: we feel that eScience technologies and activities have the potential to help bridge the boundaries between science education, science practice and public engagement with science. This has been demonstrated by the popularity of work such as the UK phenology projects, to which people of all ages and abilities, both inside and outside of education establishments, currently contribute data. Further, since it is now accepted that science is not removed from culural practice, it follows that teaching and learning methods which are effective in science may well prove useful in other disciplines, and vice versa. The BBC's People's War project is utilising what are in effect eScience methods and tools, in a project that incorporates history education and public participation in historical data collection.

Although we have concentrated in this review mainly upon learners around the transition stage between primary and secondary education, there is no reason to suppose that students in other age groups could not also benefit. One group that has often been overlooked is very young learners. Yet, as the Dental Health Simulation project has found, learning for even 5-year-old children can be enhanced by the imaginative use of ICT.

Teachers and student teachers are often involved in their own research, but their findings rarely find their way into the journals read by researchers in other fields, such as computer science, or even psychology. This type of research often involves evaluation of educational interventions, including the use of ICT. As the Sarah Earle (2004) example showed us, these insights can be valuable. Roschelle (2003) warned us to be wary of complex views of technology alongside a tendency to overly simplistic views of the complex social environment of the classroom. He advocates research into the rich pedagogical practices that arise from relatively simple technologies. This is precisely the sort of work that Earle, and other teachers like her, are undertaking. Finally, we must remember that research has costs as well as benefits to schools. Primary teachers in particular, have little non-contact time. Therefore their attendance at meetings and participation in research often depends upon the availability of teaching cover.

To our mind, the most striking finding of our review is the diversity of the projects that fall within the arena of education and eScience, bearing in mind that they currently lack a core driving funding body or set of advocates. Notwithstanding this, the passion that many leading researchers are showing in pushing through the disciplinary boundaries between eScience and education shows that the potential for community formation is ripe within the UK, although there are relatively few UK educational eScience projects as we define the term. However, among these are not only a number of ground-breaking pilots, but also national and international examples, such as the ASE’s award winning Science Across the World project, and mass participation projects such as BBC Springwatch. Although they do not label themselves specifically as eScience, these latter projects clearly fit within our definition.

We have also identified some earlier notable non-UK examples which implemented large scale schools projects using technology less advanced than that available today, showing directions for future scaling-up of UK projects. In the UK, there have been a few instances of larger-scale work in related areas which we have outlined. For example, Science Across the World has funding from GlaxoSmithKline, and Ultralab’s Schoolnet Global is co-funded by DfES and commercial partners. What appears to have happened more commonly up to now within the UK, is that small scale projects are funded by single providers. Because the scale of the project is limited, the projects run for only a short duration, participation limited to just one or two schools, and evaluation may be lacking in rigour. We therefore recommend that efforts are made first of all to raise awareness of eScience and its potential among educators and funders, and secondly to explore ways in which funders can be brought together to consider how successful pilot projects can be scaled up so that more teachers and students can take part.

4.3 SCALING UP TO A FULL SCALE eSCIENCE IN EDUCATION RESEARCH PROGRAMME

This review has shown how eScience might bring curricula based upon real-world problems into the classroom; introduce new tools to aid learning; and provide students with opportunities for feedback and reflection. It has also indicated the benefits that might be gained from cross-school, and indeed wider collaborations around science, to enable the building of inclusive local and global communities. The pioneering work on co-laboratories carried out by Pea and others in the US considered collaboration in a distributed fashion, yet appropriated technologies which are at best precursors to what is currently technically achievable under the eScience programme. UK research includes a number of exciting projects and some much broader campaigns run by institutions such as the BBC. It is clear that there is a substantial level of disparate 'pilot' work being carried out and this is an opportune time to scale up these projects to involve an order of magnitude greater users, institutions, spaces and times.

There will be challenges when scaling up some of these projects. For example, speaking from our own experience, in the SENSE project there was a very close relationship with participating schools, and researchers worked closely with teachers and children. In a large-scale project of this type, this level of involvement would not be possible. However, user engagement and participation on the design of the activities and technologies will remain crucial. Enabling multiple schools across the UK to collaborate remotely, for example sharing data captured in their own localities to contribute to a national picture, would broaden students' understanding, and encourage them to reflect on their own findings in relation to others. This opens up questions around how best to support collaborative activity such as sharing and comparing data across multiple schools and with professional scientists; and whether the needs of such diverse groups can be met simultaneously through data of the same types, using the same representations or visualisations.

There are significant further challenges that a genuinely national scale brings to these situations in terms of technical deployment and stability, but perhaps more importantly in terms of sustainability and suitability of inter-institutional communication and collaboration. Beyond technical difficulties, there are many organisational and political constraints in getting two or more schools to collaborate. This requires further investigation, with regard to how this process integrates with the curriculum or innovates acceptable change in the curriculum.

We are acutely aware that the distribution of data over networks can remove the rich contextual factors of real-world settings afforded by local experience. In such scenarios we anticipate the crucial importance of further contextual (meta)data for supporting the process of communication and for understanding the significance of particular anomalous cases. Such data provide additional resources, such as exposure to time/location methodology, to engage children in the processes of science. This starting point provides us with a broader challenge for understanding the representation of data. Sharing data between groups, communities and populations requires not only the transmission and integration of collected data, but an appreciation of the context in which those data may be verified, trusted and interpreted. In order to encourage wide-scale involvement it will be essential to develop interesting forms of scientific representation, and design flair will be required to develop the games or tasks in which students will participate.

In addition, pilot projects have illustrated the potential value for children, from interacting with scientists in order to gain further insight into their own scientific investigations. While there are existing initiatives funded by the research councils, where scientists spend a proportion of their time carrying out school visits and talking about their work, this could be enhanced through use of eScience to enable students to access experts at crucial stages in their scientific investigations in order to compare data, get feedback and ground their work in the real world. Expert scientists could suggest suitable activities to children and share their own findings. Interacting with experts however does involve various constraints, not least managing timetables of availability. There is thus a need to explore ways in which professional scientists can be made more accessible to children and teachers. Perhaps the key to such accessibility lies in enabling a reciprocal relationship, i.e. if schools can produce useful data for scientists.

As noted in our summary, there are potential benefits in engaging the broader population outside of formal educational establishments in science education. Schools can only gain if parents, relatives and others get involved. For example, one might imagine a series of school activities which run alongside large scale public events which take place at given times of the year. Of course, the scaling up of to the broader population via school projects brings to the forefront issues around trust and privacy. For instance, sensitivities around the issue of distributing images of children demand that adequate controls be put in place to avoid compromising safety, security and anonymity. The nature of such controls, together with the related ethical considerations, need to be thoroughly thought through.

In respect of addressing all these challenges, the UK is in a unique position to exploit particular avenues of existing expertise. Firstly, a strong body of researchers in the UK understand how to directly engage with user groups over a long period of time, studying and embedding the design of systems within their domain of practical use. Secondly, the UK is uniquely placed to interrelate work on mobile and pervasive computing with distributed systems work within eScience, a necessary step to integrate science curriculum fieldwork and collaborative data sharing within schools. In the following subsection, we discuss these two strengths in turn.

4.4 KEY UK STRENGTHS

Embedding eScience in practical educational practice

Successful application of future educational eScience technologies will, of course, require consideration of learning theory. For example, ‘hands on’ approaches to learning, in order to promote the understanding of scientific processes need to be integrated with factual teaching through which one can build interpretations and develop a broader understanding of topics. Such an approach may well encourage more young learners to consider entering careers in science. It may also engage still more learners, both young and not so young, in ‘scientific citizenship’; contributing in an informed way to debates about scientific topics and processes. While an interdisciplinary approach is key, so too is the involvement of ‘users’, in this case teachers and students. Designing with the people who will use the technologies to be developed will promote uptake, and enable interfaces and technologies to be tailored to the needs of those who will actually be using them. Despite the particular importance of the work within the US on educational co-laboratories reviewed above, such research typically remains within the laboratory in its initial stages, and is then assessed by blanket studies, such as online questionnaires or survey data, on larger deployment. In contrast, key researchers within the UK, many of whom have featured in this review, are able to directly engage user groups such as schools, and work with them intensively. Experience shows that such closely coupled work integrates theory and technology within their practical domain of use, and therefore provides tangible educational benefits.

Such a strength needs to be exploited, particularly where there is a notable lack of evaluation of the long term educational benefits that are afforded by the many approaches we have reviewed. Future projects should focus effort on exploring the learning opportunities provided by these types of technologies and evaluate the use of the systems, qualitatively and quantitatively as appropriate. In scaling up the projects to involve large sections of the population, opportunity is provided to capture large quantities of data. However it is also important to explore in fine detail the benefits and pitfalls that working in this way may entail for students’ learning; for example in their understanding of scientific concepts.

The meeting of pervasive and eScience technologies in education

One significant and unique feature of the UK eScience programme, is that it has been the first, and thus far only, technical community to pioneer the recognition of apparent relationships between pervasive/ubiquitous computing and grid computing (Davies et al., 2004). For example, there are researchers working in areas such as the use of grid protocols within mobile computing environments (e.g. Hampshire, 2005) and for mobile e-learning (Millard et al., 2005). This technical recognition feeds broad existing UK strengths in understanding learning with and around mobile technologies, as well as work on ubiquitous computing and learning such as the examples outlined in this review. We anticipate that incorporating activities as diverse as collecting data on field trips (such as those outlined in the Ambient Wood and SENSE projects) and then returning to the classroom to update scientific databases or share and compare data with other schools, will require the interoperation of diverse technologies. For example, the technical feasibility of using everyday technologies such as mobile phones as both environmental sensors and communications devices needs to be investigated. Consider the scenario of phones used to measure noise and light pollution through their in-built microphones and cameras, and share the data with others. Examples of this kind could open up active participation in gathering scientific data to a very wide range of the public as well as many school children.

4.5 CONCLUSION

In conclusion, an interdisciplinary approach is called for. Beyond the 'normal' eScience interdisciplinarity of computer scientists and user groups working together, this report has shown the importance of expertise which the social sciences and professionals will bring to the use of eScience in education. If the UK is to achieve a coherent national-scale programme of participation which draws on its international strengths, such an approach will necessarily include bodies such as media companies, as well as academic researchers from diverse disciplines, teachers and education professionals. Clearly a programme of this scale will require collaboration between funding providers related to each of these elements. However, this review has shown tantalising glimpses on a small scale that indicate such a programme has the potential to innovate eScience in novel directions according to UK international strengths.

We remain committed to keeping up to date with this topic. If, therefore, readers know of other educational eScience projects, (or are involved in one), which fit all or most of our criteria, but are not mentioned in this review, we would very much like to hear about them, by post or email. Please address any communications to:

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