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ICT and attainment

A review of the research literature

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ICT and attainment

Executive summary

The evidence from the literature shows the positive effects of specific uses of ICT on pupils' attainment in almost all the National Curriculum subjects. The most substantial evidence is in the core subjects of English, mathematics and science at all key stages. Other subjects require further independent studies in order to substantiate the findings currently available.

There is a strong relationship between the ways in which ICT has been used and pupils' attainment. This suggests that the crucial component in the appropriate selection and use of ICT within education is the teacher and his or her pedagogical approaches. Specific uses of ICT have a positive effect on pupils' learning where the use is closely related to learning objectives.

The positive effect on attainment is greatest for those ICT resources which have been integrated in some teachers' practices. Up to the present time there have been more subject-specific ICT resources available to teachers in English, mathematics, science and ICT than in other subjects, more use is made of such resources in these subjects than in others, and there is a greater body of knowledge about educational practices with ICT in these areas. As a result there is more evidence regarding the effects of ICT in these subjects than in others.

Smaller focused studies provide substantial evidence of the contribution made to pupils' learning by specific applications of ICT, such as the use of simulations and modelling in science, ICT and mathematics, and the use of word processing in English. Many small studies have shown consistently positive results over the last 20 years, but this does not yet extend to all types of ICT use. For example, there is an emerging body of knowledge about the effects of specific communications tools such as email and the World Wide Web, but the evidence of the effects of these on pupils' attainment is not yet consistent and extensive.

The effect of ICT on attainment in subjects

English

Different uses of ICT have contributed to some improvements in achievement in English, but the results are inconsistent and restricted by the amount of ICT use and the access to ICT resources in schools. The most commonly reported use of ICT is word processing, although other English-specific software is widely used by some English teachers. The most positive effects derive from primary pupils' use when they are at the early stages of language development, and when they have a chance to draft and then reflect on their compositions.

Mathematics

The use of ICT in mathematics has been shown to have positive effects on pupils' learning of different concepts and skills at both primary and secondary levels. These effects are most evident when the specific skills and tasks involved are measured.

Science

The use of ICT has a positive effect on many areas of attainment in science. The types of use of ICT and the enhancement of pupils' learning are much more closely related to specific concepts and skills, and tend to be more subject specific than the use of word processing in English. Through the use of ICT, pupils have improved their understanding of scientific concepts, developed problem-solving skills, been helped to hypothesise scientific relationships and processes, and improved their scientific reasoning and scientific explanations.

ICT

Innovative and challenging uses of ICT can improve pupils' data-handling skills, their ability to construct complex models and their understanding of the value of different forms of ICT. The research shows that if teachers were to provide opportunities for pupils to carry out in-depth investigations with, for example, appropriate modelling environments, then pupils could reach higher levels of abstraction and competency in the field of ICT.

Humanities

There is evidence to show that the use of simulations can enhance pupils' reasoning and decision making in geography, history and economics, although there is less research available in these areas than in the core subjects. There is little evidence of ICT being used widely in primary schools for the teaching of geography or history.

Modern foreign languages

There is evidence of positive effects of specific software, such as software providing foreign language simulations, on attainment in modern foreign languages. As with the teaching of English, much of the success reported in the literature is linked to particular sub-skills of language learning such as word recognition and vocabulary building. The most consistent evidence is where specific

skills have been measured that are closely related to those used through the ICT application.

Art, music, business studies and physical education
Comparatively little research has been published about the effects of ICT in art, music, business studies and physical education. Some studies provide evidence of the enhancement of pupils' learning through specific ICT applications such as music synthesisers in music, digital imagery software in art and through developing a range of ICT skills in business studies.

The impact of ICT on motivation and attitudes

Many studies report an improvement in pupils' motivation and attitude to learning, shown through an increased commitment to the learning task and greater interest in the subject, and through pupils taking more responsibility for their learning and making sustained efforts in difficult tasks. Although much of this evidence was gathered through observations and questionnaires, more substantial evidence is also provided through attitude tests.

Factors affecting attainment

Many factors were found to affect, and be inextricably linked to, pupils' ICT-based learning experiences.

Teachers' pedagogies
Teachers' pedagogies have a large effect on pupils' attainment. They influence the selection of the ICT resource, the preparation of the lessons, the way the resource is used with pupils in lessons, the level of guidance and intervention, and the level of integration of ICT use within the teacher's subject. Many of the studies show that insufficient understanding of the scope of an ICT resource leads to inappropriate or superficial uses in the curriculum. Further analysis of the available research regarding ICT and pedagogy can be found in the companion to this publication (Cox and Webb, 2004).

The use of ICT in different school settings
Clearly, the extent and range of uses to which ICT is put will influence the measurable effect on attainment. The majority of uses of ICT in the research literature are limited to a small range of ICT resources used by individual teachers. These resources include simulations software in science, word processing in English, and Logo[1] in mathematics.

There are very few studies which report on a single teacher using a whole range of ICT resources in the curriculum for a particular subject (including the ICT curriculum). Although there are individual studies on the use of other types of ICT resource, such as music synthesisers, measurement and control software, and English software, the richness and breadth of ICT resources used as reported in the literature is disappointingly limited.

There is a growing body of research into pupils' use of the internet for sending and receiving emails, for using chat rooms, and creating websites. Researchers have consequently analysed email texts and websites to assess pupils' development of new ways of communicating their ideas and presenting information.

The use of ICT in informal settings
Using ICT at home or after school can contribute to the pupils' learning; however few schools and teachers have yet been able to integrate pupils' home use of ICT with their school use. Despite this, teachers report a number of benefits for the home use of ICT by pupils. Pupils can share ideas and discuss homework tasks with their peers and also their teachers via email, chat rooms and websites, which may usefully challenge their own understanding.

Age of pupils
On the basis of the research literature, there is no conclusive evidence that the use of ICT has a greater effect on any particular age group of pupils. However, pupils of different ages may have a different level of access to ICT (for example, at primary compared with secondary level), and there may be uses of ICT resources which are inappropriate for pupils either in relation to their age or ICT ability.

Social and cultural backgrounds
There are some studies which measure the frequency of access to ICT among different social and ethnic groups, but there is no clear evidence of the effects of inequalities in access due to social and cultural background on pupils' attainment.

Research methods
The use of ICT has often been influenced by the way research has been conducted. Naturalistic studies

[1] Logo is a programming language designed as a tool for learning, most commonly used in mathematics and science.

investigate how teachers use their existing ICT resources, whereas intervention studies are those in which the researchers have introduced a specific ICT resource, for example, by giving teachers laptop computers. In intervention studies, the settings in which the ICT is used as well as the teachers' pedagogical practices are affected, and this will affect the outcome.

Factors which can affect findings include:

- quality and depth of ICT use included in the study
- design of the tests to measure attainment
- scope and nature of the observations of pupils using ICT
- the ways in which pupils' products are analysed
- design and analysis of pupils' and teachers' questionnaires and records.

Furthermore, in some studies there may be a mismatch between the methods used to measure effects and the nature of the learning which is promoted by the specific uses of ICT. Researchers have looked for improvements in traditional processes and knowledge instead of new reasoning and new knowledge which might emerge from the use of ICT. It may be that a clearer picture of the impact of ICT will emerge if the methods used to measure attainment are more closely related to the learning experience promoted by a specific type of ICT use.

Background and further reading

This report is published alongside a companion literature review on ICT pedagogy (Cox and Webb, 2004). The reports complement each other and provide a foundation for understanding the research literature on ICT attainment and pedagogy.

The full report on which this publication is based is available on the Becta Research website [www.becta.org.uk/research/].

ICT and attainment

Introduction

Background to the study

This study was commissioned by the British Educational Communications and Technology Agency (Becta) on behalf of the Department for Education and Skills (DfES) to investigate the effects of ICT on attainment, based on evidence from the published research literature. The aims of the study were:

- to identify and use reliable, well documented sources of evidence from the published literature
- to consider evidence from this wider research literature relating to ICT and attainment to complement the ImpaCT2 findings (Harrison *et al.*, 2002; Comber *et al.*, 2002; Somekh *et al.*, 2002)
- to identify the range of environmental, contextual and institutional factors that may have an impact on the association between ICT and improvements in attainment
- to provide an analysis of key issues revealed from the literature review for further research.

This study is one of two literature reviews, commissioned as part of the ICT and Attainment project. The other review (Cox and Webb, 2004) considers the research evidence relating to ICT pedagogy. Both studies were carried out by the same research team, and many of the procedures and methods were the same for both studies.

Approach to the literature review

The study involved collecting data from various sources published in the English language, largely from 1990 to the present day, including quantitative surveys and statistical publications, qualitative or case study data, and previously published meta-analyses (studies which aggregate the findings from many other studies). The emphasis was on identifying work that was both original and nationally important. Additional attention was also given to the accuracy of reported results, the variables considered and the applicability of results.

The following were reviewed:

- studies investigating the ways in which ICT has been used and the attainment outcomes for Key Stages 1–4
- specific studies of clearly defined uses of ICT for learning particular concepts, processes or skills
- meta-studies which have measured the large-scale impact of ICT on attainment
- research evidence relating to specific curriculum subjects
- research evidence relating to specific social characteristics, for example age, gender, class, ethnicity
- evidence relating to factors which might influence the learning outcomes, such as teachers' pedagogies, the nature of the ICT environment, and the level of ICT resources.

In order to measure the effects of ICT on attainment it is necessary to identify the actual aspects of ICT which the learners will experience, for example data handling. Many studies do not take sufficient account of the necessity to design instruments which can measure the learning gains promoted by a particular task or activity. Previous evidence has also clearly shown that the effects of an aspect of ICT on attainment will be dependent upon the context in which teaching and learning take place, and the ability of the learners to use the technology. Therefore the project team recorded details of these variables where they were reported, although not all studies report such details, particularly in large-scale quantitative studies.

It was not possible within the time-scale of the project to review all the published evidence. However, in order to use the evidence from this broader literature the project team produced two literature bases. The first is a list of references to which this report specifically refers, which are included in this publication. These include a wide range of empirical findings and theoretical perspectives. The second is a wider bibliography, which has informed and underpinned the approach and analysis. This is available on the Becta Research website [www.becta.org.uk/research/]. A more detailed account of the procedures and sources used can be found in the full report on which this publication is based, also available on the Becta Research website.

The project team

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Section 1 ICT and attainment – an overview

The effects of ICT on attainment

Empirical evidence of the role of ICT in educational attainment has been the holy grail for some researchers and many policy-makers for many years. It is understandable that those responsible for extensive investment should seek to establish measurable outcomes. However, it is clear from much of the available research to date that such evidence, if it is to be convincing, will take time to emerge and may not be as clear-cut as some observers might have hoped.

According to Laurillard (1994, p.46) 'There is a persistent discrepancy between the questions asked of evaluation studies in new technology, and the conclusions they come to.' In her research into ICT and attainment, Laurillard has repeatedly shown that the context of the use of ICT determines any effects that ICT may have on attainment, and that it is extremely difficult to separate the uses that new technologies are put to from the context of their use. This is supported by Joy II and Garcia (2000), who suggest that it is not the sole effect of ICT on learning gains which should be studied, but the combination of ICT use with particular pedagogical practices, a point which has been echoed elsewhere (Kennewell, 2001). As a result, this review of the literature encompasses issues relating to the research methodologies used by studies into the effect of ICT on attainment rather than merely the findings from such studies. This review reports evidence of a positive effect of ICT on pupils' attainment where the research methods have been specifically designed to relate to the particular types of learning experiences promoted by the use of ICT.

A number of large-scale projects, meta-studies and small-scale circumstantial studies (Becta, 2001a; Becta, 2001b; Becta, 2003) have been conducted. There has been considerable discussion regarding the methodological basis for some ICT research and ICT policy making (Selwyn, 1997; Selwyn, 1998b; Selwyn, 2001; Reynolds *et al.*, 2003). Evidence from the literature has shown that methodologies have sometimes limited the effectiveness of research. For example, a Finnish study of 515 school pupils (Hakkarainen *et al.*, 2000) suggested that ICT had made learning in secondary schools more effective and meaningful, but this suggestion was based on data collected from pupil self-assessment questionnaires. Such methods do not assess actual learning outcomes but only the pupils' perceptions of the experience and its possible benefits to their learning.

A Scottish study (Condie, 2002) sought to discover the extent to which ICT resources contributed to learning for almost 3,000 pupils in 80 secondary schools. Questionnaires and test booklets were used to assess the benefits of using these resources but the only gains recorded were in ICT knowledge and skills.

Other research has focused on gains in learning in particular subject areas. For example, a US project (Robinson-Staveley and Cooper, 1990) found that the use of ICT led to improved writing by pupils. This begs a number of questions, however, particularly about the definition of 'writing' used. The setting was a US composition-writing class, a very different context from, for example, a literacy hour lesson in the English schools' curriculum. Such findings are often interesting, but raise issues as to how generalisable they are.

Researchers in the USA conducted a national study of teachers' pedagogy and use of computers. The Teaching, Learning and Computing (TLC) survey, funded by the National Science Foundation and the US Department of Education, included more than 4,000 teachers and 1,100 schools. A variety of reports and academic papers have been published as a result of these activities (Becker, 1999).

A subject that is often studied within this area is ICT itself, or more frequently computing as a subject. A project in Israel considered the role of animation in the teaching of programming (Ben-Bassat Levy *et al.*, 2003). It was found that the use of a multimedia tool had a measurable but small effect on attainment. The team reported that the most able pupils did not need the animation tool, and the lower ability pupils could not use it. However, the researchers did feel that the tool was useful for some pupils in the middle ranges of ability, although they provide no empirical evidence for this supposition.

Many previous research studies have reported on the use of modelling to support the teaching of programming (Lavonen *et al.*, 2003) and causal reasoning (Mellar *et al.*, 1994), and have reported significant success, as is explained later (p.25).

It is also important to note that the research evidence revealed in a study can sometimes depend upon the

expectations of the researchers. For example, those with an optimistic view of the potential for ICT to raise attainment levels may present their evidence in a different way to researchers with a more pessimistic view. Reynolds *et al.* (2003) analysed the reasons for excessive optimism concerning the potential of ICT to enhance levels of pupils' achievement. They compared the 'optimist-rhetoric', a large body of work which supports the idea that ICT raises standards of pupils' achievements, with 'pessimist-rhetoric' and academic research using a range of research methodologies that have a proven track record in terms of reliability. This 'constantly throws up evidence that refutes the optimist-rhetorician claims.' (Ibid., p. 152.) They also carried out a small-scale study and found 'The comparison of the Ofsted standards...with the apparent realities found in the research on secondary schools, seems to show a high level of disparity between schools, regardless of socio-economic grade... There is cautious ground for optimism to be drawn from this study if we adopt an optimist-rhetoric stance. 83% of teachers interviewed in schools said they believed that ICT can raise standards… Yet, we wonder, why is this a belief instead of a reality after the investment...over the past twenty years?' (Ibid., p. 152.) They saw a pressing need to subject the optimist-rhetoric to the objective examination of academic research. 'Where is the evidence that the ICT improved the pupils' performance? – a methodological nettle that the ImpaCT2 research team noted as being outside their remit to grasp.' (Ibid., p. 153.)

The frequency and range of use of ICT in schools and the home

Apart from the ImpaCT2 study (Comber *et al.*, 2002; Somekh *et al.*, 2002), comparatively little attention has been paid to the use of ICT in the home, although studies are beginning to be published (Mumtaz, 2001; Mumtaz, 2002). Personal digital assistants (PDAs) have been used in some schools as a way of providing access to ICT resources at home and school, and as a means of linking the two sites together. Little research has yet been done on the use of PDAs, but one study (Hennessy, 2000) found little evidence of any improvement in learning when using tools on a PDA compared with using the same tools on a desktop computer, although the pupils were motivated by access to the PDAs.

Other studies (Robertson *et al.*, 1997; Newhouse and Rennie, 2001) described issues such as the difficulties experienced by pupils using laptops which could be taken home, or the failure of pupils to make use of ICT facilities at school (Selwyn, 1998a), even when their home use had shown them the potential benefits.

An evaluation of the Multimedia Portables project in Wales (Thorpe and Roberts-Young, 2001) identified some of the factors likely to lead to success in this area, which included supporting the development of teachers in their application of the technology, carefully selecting appropriate packages for use in the classroom, and encouraging pupils to collaborate fully and with others online.

The ImpaCT2 project included 15 case studies in which the pupils' and teachers' specific uses of ICT were recorded, including pupils' home use (Comber *et al.*, 2002). The researchers found that many pupils had more advanced computers at home than they had access to at school. There was evidence of some home use which contributed to pupils' learning at school. This included researching on the internet for homework, sharing ideas for answering questions using chat-rooms and text messaging on mobile phones, and exchanging ideas about school work by email. The teachers also reported that pupils' home use of ICT for their school work needed to be guided to enable the pupils to focus on the topics and the purpose of the learning activities. Another contribution to school work resulted from the alleviation of the shortage of computers for pupils at school. Teachers, who were still finding it difficult to access computers often enough at school for their subject teaching, found that pupils' home use could supplement their use in schools, particularly when they could not access computers outside lessons at school.

Differential access and use in relation to social characteristics

Provision of ICT resources in rural areas has been a major consideration for some parts of the UK such as Scotland and for some other countries. In Norway, a particularly sparsely populated country by European standards, proposals have been put forward for municipal ICT schools which will support other more rural districts (Hartviksen *et al.*, 2002), and similar discussions have taken place in Finland (Husu, 2000). Video conferencing has also been shown to be successful in these contexts (Thorpe, 1998). In many ways, this is a variation of the specialist school model[2] that has gained credence in the UK in recent years.

Attention has also been paid in Norway to the potential of email for supporting student teachers on placement (Hoel and Gudmundsdottir, 1999), an approach echoed in other studies (White and Le Cornu, 2002).

The changing nature of the provision of educational ICT resources

During the late 1980s the US educational software marketplace was dominated by integrated learning systems, extensive software resources developed over many years, providing a managerial support system and often based on a behaviourist or quasi-behaviourist view of learning. Over time, much research on this topic had moved on from attempting to measure learning outcomes (Bentley, 1991; Becker 1992a; Fischer, 1996) to considering the ways in which these systems might be improved and made more effective (Becker, 1992b; Maddux and Willis, 1992; White, 1992; Hativa and Becker, 1994).

During the mid-1990s the UK Government invested in a large-scale evaluation of integrated learning systems. The researchers involved in the project issued a series of reports and also published academic papers which commented on their involvement in the evaluation and its outcomes. The first report of the UK evaluation (Detheridge, 1994) was written by the National Council for Educational Technology (NCET) and was broadly positive. It was reported that children had made learning gains in mathematics, although not in reading. Interestingly, learning gains were inversely related to the children's own perception of their progress.

By the second report (Avis, 1996), also written by a member of staff at NCET, an element of caution was creeping in. This second phase differed considerably from the first one and was in effect a new research project. A larger group of schools was involved, and the emphasis had changed to the transferability of the learning gains that had been identified.

The third report (Wood *et al.*, 1999) added other reservations, particularly in the statement from Becta (the successor organisation to NCET) which formed the foreword. After correctly pointing out that the evaluation had been the largest independent study of integrated learning systems in the world, the foreword went on to report an important reservation that the gains noted did not appear to be automatically transferable. The researchers reported that the software used was mainly seen by pupils and teachers as being successful at teaching core mathematical and English skills but not all such successes were measurable through the subsequent tests or examinations (Wood *et al.*, 1999). The report went on to indicate that pupils certainly learn something from integrated learning systems, but that it can be difficult to establish the exact nature of the learning. Effects on motivation and behaviour were marked, but there was no evidence that they transferred to other contexts. More than this, the report suggested that exclusive reliance on integrated learning systems as preparation for Key Stage 3 and GCSE exams might even have a negative effect.

Other research arising from the UK evaluation (Galton *et al.*,1997) tended to focus on particular aspects of classroom ethos and pedagogical change rather than trying to measure learning gains. Recent research from the USA (Brush *et al.*, 1999; de Castell *et al.*, 2002) has shown that the more explorative and problem-solving aspects of some integrated learning system products are more effective than the traditional foundation activities, and that a rethinking of the role of integrated learning systems may also lead to a helpful re-examination of the use of ICT in education as a whole. One message appearing more frequently in the integrated learning systems research (Powell *et al.*, 2003) is an indication that not only does success with integrated learning systems relate to the pedagogical approach adopted by the teacher, but that it may also depend, perhaps paradoxically, on pupils being self-directed enough to make appropriate use of the resource.

Specific studies of particular clearly defined uses of ICT for learning particular concepts, processes or skills

Studies have been conducted for more than 30 years into the effects of ICT on attainment. It has often been the case that such studies report limited evidence of increased attainment, yet the researchers indicate that fundamental but hard-to-measure change may have taken place.

An Israeli study in the early 1990s (Klein and Nir Gal, 1992), which looked at very young children, found little

[2] In the UK, academies are an example of specialist schools. These follow a broad and balanced curriculum, but with a particular focus on one or more areas. Possible specialisms include technology, science, art and sport.

evidence of the kind which was anticipated, but the researchers reported that the group using computers paused more frequently to think and talk about what they were doing.

Another Israeli study (Offir and Katz, 1990) reported that teachers who were willing to take risks were most likely to be effective users of ICT, although this was within a computer-assisted instruction[3] (CAI) framework rather than within a model of more general ICT-supported learning. There are echoes here of Seymour Papert's characterisation of the lone enthusiastic teacher in the first wave of a new technology, followed by unquestioning acceptance of technology by the many and only then a critical awareness by the many of the potential of the new technology (Papert, 1996).

A more complex problem encountered when considering the research literature in this area is the difficulty of making transparent the underlying assumptions about learning processes. Much of the academic writing from the 1980s and early 1990s, especially from the USA, seems to be grounded in assumptions about transmission of information rather than situated learning[4] or the collaborative enhancement that is achieved through scaffolding.[5] Other writing (such as that of Laurillard, 1998) may be based on particular views of the learning process, seeing it as an iterative cycle of discussion, interaction, adaptation and reflection. In the Laurillard paper, the author goes on to argue a convincing case for the educational value of using multimedia to learn about narrative.

The problem revealed by these studies is the frequent mismatch between the methods used to measure anticipated gains and the nature of the learning which is promoted by the use of different forms of ICT. In other words, it is suggested that researchers have often measured the 'wrong' things, looking for improvements in traditional processes and knowledge instead of new reasoning and new knowledge which might emerge from the particular use of ICT.

Meta-studies

The early days of the use of IT and ICT in schools were characterised by overviews which were optimistic in tone, but suffered from an absence of suitable data (Hawkridge, 1990). However, many important issues were raised and much was achieved through these publications. NCET and later Becta have published a number of meta-studies that have attempted to bring together published research and interpret it for practitioners and policy-makers. One of the first publications of this kind was *IT Works* (Brown and Howlett, 1994), followed later by *IT Helps* (Abbott, 1995). These publications referred to highlights of previous published research and indicated evidence of the positive impact of ICT on attainment, but did not contain detailed information about methodology or findings. Similar publications have appeared which deal with particular areas of the curriculum (McKeown and Tweddle, 1994), and specific subjects (Selwyn, 2002; Wegerif, 2002). A common outcome of these publications is the contribution of evidence of specific uses of ICT in learning, rather than large-scale evidence of the effects of the integrated use of ICT on attainment.

A recent paper by Lin and Hsieh (2001) reviewed the range of literature related to the web and pedagogical practices. The Second Information Technology in Education Study (SITES) has also reviewed the evidence regarding ICT and pedagogy (Pelgrum, 2001). These reviews described a range of pedagogical practices, but the activities often took place with minimal input from the teachers compared with other more conventional activities. Most of the learning activities involved searching for information on the internet. Not many other uses were made of the internet (such as guided online debates or using interactive software).The most substantial evidence of ICT and attainment is within specific subject areas, and this is reported in the following sections.

[3] Computer-assisted instruction refers to the use of computers for drill and practice, tutorials, and simulations – either as stand-alone products or alongside classroom instruction.

[4] Situated learning is that which takes place in a relevant context. Advocates of situated learning argue that this is the only way in which pupils can gain 'active' knowledge, which can be applied to different tasks, as opposed to 'inert' knowledge, which results from abstract, out-of-context learning, and is less easy to apply to new situations.

[5] 'Scaffolding' means that pupils build up knowledge and understanding by linking new concepts to those previous understood through a mental framework of linked concepts.

Section 2 ICT and attainment in subject areas

Much research on ICT in schools has related to specific subjects, or to ICT itself (Selinger, 2001), although a few studies (Christmann *et al.*, 1997) have looked at a range of subjects or at the whole curriculum. This section examines the evidence relating to ICT and attainment in specific subject areas.

English

Although teachers of English in the UK may not have been early adopters of ICT, they have been exposed to the issues regarding use of ICT for many years (Monteith, 1993; Scrimshaw, 1993), and there continue to be calls for first language teachers, above all others, to be provided with the technology that is now essential to their job (Yaghi, 2001).

Teachers have been loyal to particular software, especially where this has been debated and considered in subject journals. One example is an exploratory simulation of a literary text, also the subject of a recent paper (Birmingham and Davies, 2001). Although the focus in the paper is as much on evaluating the tool as it is on measuring learning gains, it sheds light on the practices of teachers when using such software.

One study of the use of computer-assisted instruction for reading in a US elementary school (Erdner *et al.*, 1998) showed gains only on the part of the boys, while another study (Feldmann and Fish, 1991) showed no gains at all.

There are considerable research findings to suggest that recently qualified teachers of English see ICT as central to their profession (Tweddle, 1992; Tweddle, 1995; Goodwyn *et al.*, 1997; Tweddle, 1997; Rees, 2002), and that they welcome the opportunity to participate in sharing their experiences online (Leach, 1997).

As has been shown since the early 1990s (for example, Kay and Mellar, 1994), very few new teachers feel totally prepared to use ICT in their teaching when they arrive in their first school, and the support and encouragement they may or may not receive there is crucial to their development as mature, informed users of ICT. It has also been shown that it is highly effective if new teachers see good ICT practice modelled for them early on in their school placement (Trushell *et al.*, 1998).

Much other research into the use of ICT within English has been grounded in a media studies or media education background (Barna, 1995; Lachs, 2000; Garner *et al.*, 2002). Typically, this research has had an optimistic, uncritical view of technology, although this has changed considerably in recent years. Where there has been an attempt to measure attainment of pupils who are using multimedia authoring (Kafai *et al.*, 1997), this has sometimes been done without control groups or with very small sample sizes. Much of the research in this area has celebrated the use of ICT for media production outside usual schooling settings (Sefton-Green, 1998; Sefton-Green, 1999) and bemoaned the diminishing mention of ICT in the UK English curriculum (Turner, 1994).

Much of the research on reading and ICT has tended to focus narrowly on particular sub-skills, particularly those that appear to be readily assessed such as phonological awareness[6] and word recognition. It is interesting to note that an earlier research paper from Switzerland (Karrer, 1991) attempted to measure learning gains among 72 children as a result of using a range of educational software. The only measurable gains were from the use of vocabulary-building programs in English (English as a foreign language) and Latin.

One study of 54 early-years children in the USA (Barker and Togesen, 1995) reported significant gains in phonological awareness and word recognition, and also indicated that some of these improvements were measurable in the results of reading tests dealing with other aspects of attainment. However, even this group of researchers did not find that their results indicated more achievement among this group than would be expected from a group taught by an experienced teacher.

The two ImpacT large-scale quantitative studies also found evidence of a positive contribution to attainment in English in some contexts. In the case of the first ImpacT project (Johnson and Trushell, 1993), there was a statistically significant[7] effect of using word processing on attainment in English for pupils aged 8–10, but only a partial non-significant effect for pupils aged 12–14.

[6] Phonology is a branch of linguistics. It is concerned with the study of the sound systems of languages.

[7] Statistical significance is a way of measuring how certain we can be regarding a particular finding. All results obtained by statistical methods are open to the possibility that they might be the result of 'statistical accident'. Statistical significance is determined by the probability that this accident has not happened.

The pupils' English was assessed through various essay-writing tasks, which were graded by two independent English teachers. The quality of the essays was also assessed through measuring the rates of cohesion and coherence in the pupils' texts and the errors in spelling. The main finding from the study of primary pupils' English was that the frequency of use of ICT in the pupils' English lessons affected their achievements in English. There was some positive contribution from the use of word processing in the 'high IT' primary classes relative to the ratings given for content and cohesion. When pupils composed directly with word-processing facilities, they were more prone to summarise and remove redundant information. (Johnson and Trushell, 1993, p.114.) However, the pupils reported that they used ICT at most three to five times a term (for each pupil), sometimes for only a few minutes. At secondary level the results were less conclusive, partly because of poor returns on the English essays, and again because of the limited use of ICT in English lessons. With such infrequent use of ICT in English, it is surprising that there were any measurable positive effects on attainment.

Some years later, the ImpaCT2 project also found mixed results for the effects of ICT on pupils' attainment in English. At the primary level there was a statistically significant impact of ICT on the Key Stage 2 English tests, but not at Key Stages 3 or 4 (Harrison *et al.*, 2002). However, attainment was measured through the national key stage tests which at Key Stages 3 and 4 do not focus on creative writing or composition. Although it is not possible to tell what the types of ICT use in English were for the secondary pupils from the large-scale study, the case studies show that the predominant use of ICT in English was for word processing (Comber *et al.*, 2002), which would not have had a large impact on the English language knowledge being assessed at the secondary key stages. The research also shows that the frequency of ICT use is still very low in English and other curriculum subjects, so it is not unexpected that there was not a large effect revealed.

The arrival of digital audio files, which enable sound files to be stored and played back on a computer, led to a flurry of interest on the part of publishers and then researchers in the potential of talking books,[8] although these have not gone on to become quite as prevalent as expected. Nevertheless, work at the Open University (Lewin, 1998) showed that talking books can help with single-word recognition or sight vocabulary, but that they are largely ineffective at building phonological awareness.

Another UK study in this area (Underwood and Underwood, 1998) chose to focus on the animations and other interactive facilities which enhance the ICT-based text in a talking book. It was found that, although children enjoyed these features, any skills learned did not transfer to the written task, but neither did they distract the pupils from the main narrative.

However, researchers considering the value of total-immersion virtual reality simulations (Whitelock *et al.*, 2000) found that there was a risk of the experience affecting the learning outcomes. While recognising the motivation of a sense of 'being there', they were concerned that this might 'take up too much of the user's attention and produce cognitive overload when it comes to understanding conceptual notions.' (Whitelock *et al.*, 2000.)

The quality of computer-generated speech was an issue for another study (Lynch *et al.*, 2000) where researchers measured the effects of a support program designed to help with the teaching of reading. Considerable gains were shown, at least as measured with traditional (and limited) test instruments producing reading ages, reading speed and so on. Although the sample involved only eight pupils, this led the researchers to conclude that such software may have potential for all children in secondary school experiencing difficulties with reading.

Word processing has, not surprisingly, been a central focus for researchers working within English (Murray, 1992; Wolfe *et al.*, 1996). As at least one recent paper (Mumtaz and Hammond, 2002) has shown, word processing is still not fully embedded, or used effectively, in many primary school classrooms in the UK. In part this is because many teachers and parents continue to think of word processing as a desktop-publishing tool or printer, which has marginalised its greater potential as a means of drafting and revising, despite this model having been proposed in curriculum documents for many years.

Allen and Tompson (1995) considered the use of word processing in a networked learning environment in a school and how this might offer access to real audiences

[8] Talking books are designed to be read on a computer, with a combination of features such as text, pictures, photographs, drawings, animations, sound and video, and often the option of having the computer read out the text for the user. They are usually stored on CD-ROM.

for writing. The study reported significant improvement in writing, although some of the measures used, such as word counts, may relate to text production rather than writing in a holistic sense as it would be understood by a teacher of English. The researchers also reported greater engagement in writing on the part of boys in the networked group compared to those in the control group.

A related project (Haymore *et al.*, 1992) investigated the effects of the use of ICT on classroom management issues. The study highlighted three issues relevant to practice and research: teachers need to continue to develop classroom management skills; educational change takes time; and individual teacher change is not always in one direction. Data from this five-year study showed that even when classroom environments are drastically altered and teachers are willing to innovate, change is slow and sometimes includes temporary regression. 'Teachers need to have time to move through different stages of concern in order to utilise the technology space...to their advantage.' (Ibid., p.503.)

More recently, computer-mediated communication has been a feature of research in English classrooms. Experiences in Northern Ireland (Clarke and Heaney, 2003) have suggested that valuable understandings and skills can be developed through the use of asynchronous communication,[9] although the results were not supported by any standardised test scores.

A US study of 160 undergraduates (Barker and Pearce, 1995) attempted to specify 17 aspects of writing that might be supported and developed by the use of ICT. Pupils were randomly assigned to a group writing by hand or one using computers. Students in the computer-using group were found to make fewer punctuation errors and their work was easier to read. However, they also used significantly more passive constructions and what the researchers described as 'trite expressions'. It is difficult to be sure about the extent to which these outcomes are related to the technological intervention rather than to past and present teaching styles and expectations.

There is a growing body of research (for example, McBride and Seago, 1999; Cummins, 2000) related to the use of ICT when teaching English as a foreign language (TEFL), English for speakers of other languages (ESOL) or English as an additional language (EAL) (Silver and Repa, 1993; van Haalen and Bright, 1993; Ward, 1996), or the equivalent in non-English-speaking countries. A study of pre-school children of Turkish origin in the Netherlands found that the use of ICT did support their language learning (Segers and Verhoeven, 2002), but that other activities were equally important.

Sadeq (2002) measured the effects of using a range of computer-assisted language-learning software, mainly based on role-playing simulations, on Kuwaiti pupils learning English as a foreign language. She measured the impact on attainment through a quantitative study of over 100 pupils, using tests both before and after the software was used, and found that the greatest gains were for vocabulary skills, with relatively little improvement in grammar. Although this study was conducted with 17-year-old pupils, the results showed the importance of designing tests which would measure separately a range of linguistic skills rather than measuring a compilation of a range of language skills, as in several previous studies.

Much less attention has been paid to the role of ICT in promoting talking and listening (Dawes *et al.*, 2000) than to its potential for supporting the skills of reading and writing, which are more prominent in the curriculum. A more inclusive approach was taken by a recent wide-ranging review of literature in the area of language and technology (Milton, 2002), and ICT has been considered in some depth by writers concerned with global literacies (Selfe and Hilligoss, 1994).

One focus within this area has been on those aspects of writing which are changed, supported or developed by the creation of online resources such as personal home pages (Abbott, 1998; Abbott, 1999; Abbott, 2001). Ideas which have migrated from human–computer interaction have led to reformulated concepts of writing as an act of graphic design (Sharples, 1999) or as a visual design practice which is developing its own grammar as well as vocabulary.

During the last 20 years the growth in the range of ICT resources has also led to an expanding range of representational systems and different types of human–computer interface. This has extended the specification of knowledge and knowledge domains that learners now meet in education (Anderson, 1978; Merrill,

[9] Asynchronous communication involves participants creating mesages for others to read, but replies to those messages may not be instantaneous; any amount of time might lapse between each individual contribution to a conversation.

1994). From the early days of ICT simulations it has been recognised that ICT software can provide new representation systems which require different understandings of the way knowledge is codified and constructed (Laurillard, 1978, 1993; Sakonidis, 1994; Cheng, 1999). The different types of human–computer interaction required of the learner also require an understanding of the new types of literacy which these representations present. This has implications for the instruments we use to measure the effects of ICT on attainment.

The rapid increase in the ability of computers and networks to handle video has led to activities such as the Becta Digital Video project, where teachers reported that this technology had helped pupils assimilate and understand concepts (Reid *et al.*, 2002). However, in this case, the findings were based on teachers' perceptions rather than test scores.

The effects of ICT on attainment in English – conclusions

There is evidence that different uses of ICT have contributed to some improvements in achievement in English, but the results are very inconsistent and restricted by the rate of ICT use and access in schools.

The most predominant use of ICT across the research projects has been word processing, although other English-specific software is widely used by some English teachers. There are interesting studies which show word processing to have both positive and negative effects. One such study is that by Barker and Pearce (1995), which found that undergraduates made fewer punctuation errors but more passive constructions when using word processors.

However, Mumtaz and Hammond (2002) found that word processing was not fully embedded in the English curriculum, and that often word processing was used superficially with little opportunity for pupils to draft and redraft, through which process the most positive effects have been identified. The most positive evidence arises from primary pupils' use of word processing when they are at the early stages of language development, and when they have a chance to compose and reflect on their compositions.

One of the limitations of measuring the effects of ICT in English has been the difficulty in designing appropriate ways of measuring attainment. Some researchers have used specific measures such as coherence and cohesion of the text, using markers of cohesion, while others have used experienced teachers to assess the quality of the written work produced. There is not yet a clear consensus of how to measure the quality of written English, nor of composing, interpreting, orating and other skills which might also be affected by the use of ICT in English.

Mathematics

In many ways, little seems to have changed since Becker's 1989 International Association for the Evaluation of Educational Achievement (IEA) survey in the USA (Becker, 1991), which reported little use of computers being integrated into mainstream secondary mathematics teaching. Where there were only a few computers in a classroom, they were often used to remedy deficiencies or as a reward for finishing other work; where there were a large number, the function most often quoted was 'learning to apply mathematics'.

By 2000, Clements (2000), also in the USA, observed that pupils were using computers only occasionally, and, often, less able pupils never got to use the computer. Less than one-quarter of pupils' working time was regarded as productive.

In the UK, the recent ImpaCT2 project (Harrison *et al.*, 2002) reported that at Key Stage 3, 67% of pupils never or hardly ever used ICT in mathematics lessons, and at Key Stage 4 the figure was over 80%.

In a series of articles arising from a project in Leeds, Monaghan *et al.* (1999) reported that ICT was used, on average, during one lesson in every four. However, pupils' enthusiasm for using ICT declined as examinations approached.

Ruthven and Hennessy (2002) provided an overview of the studies on the integration of computer use into mainstream teaching practices and teachers' thinking. This was part of an analysis of the pedagogical ideas underpinning teachers' accounts of the successful use of computer-based tools and resources to support the teaching and learning of mathematics. Ruthven and Hennessy found that the level of use and integration of ICT into mathematics teaching varied among teachers, and that the majority were not using ICT frequently as an integral part of their curriculum.

Two of the major UK studies that included an investigation of the effects of ICT on pupils' attainment in mathematics are the ImpacT and ImpaCT2 studies. The first ImpacT project (Watson, 1993) developed a range of

assessment methods based on those used by previous large-scale projects, as well as new ones which were specifically designed to measure attainment in conceptual understanding and intellectual processes. These included:

- different subject- and topic-based tests, conducted over two years, testing pupils' subject knowledge at the beginning and end of the period
- a series of linked case studies to investigate the effects of teachers' pedagogies on pupils' use of ICT and the consequent learning outcomes
- a study of the uptake and use of ICT by all the teachers and pupils in the study, which involved new data-collection instruments, including pupils' record sheets (collecting data on the types of ICT use and on where this occurred).

In the case of mathematics, pupils aged 8–10 and 14–16 in classes which were using Logo[10] and subject-based mathematics software achieved statistically higher scores in tests than those pupils who were being taught similar concepts through traditional methods. The results provided significant evidence of a positive impact of ICT on pupils' learning in mathematics in classes where ICT was being integrated into the mathematics curriculum. The project's mini-studies provided additional evidence of positive effects of ICT on attainment – in mathematical reasoning using Logo, and Boolean logic[11] skills using databases.

In the recent ImpaCT2 study, evidence was also found showing that ICT had a positive relationship to pupils' learning of mathematical skills (Harrison *et al.*, 2002), and the results varied according to the amount and type of use of ICT in the mathematics curriculum. High users of ICT at Key Stage 3 outperformed, on average, low users of ICT in mathematics, but differences at Key Stage 4 were slight. However, this aspect of the research was only designed to establish whether correlations existed between ICT use and attainment, rather than to investigate causal relationships.

One of the limitations of the ImpaCT2 study was the way in which data were collected on the pupils' uses of ICT. Reports were collected once a term from the pupils for the longitudinal study, but this did not give sufficient detail (except through the later case studies) to show the specific types of ICT use and the extent of use in any one lesson. The first ImpacT project collected pupils' and teachers' reports on types, frequency and curriculum uses of ICT each week over a two-year period, augmented by a series of longitudinal case studies. This provided enough information to be able to relate the uses of ICT more specifically to attainment in mathematics (Watson, 1993).

According to Hennessy and Dunham (2002), studies involving contrasting control and experimental groups using technology are fraught with difficulties because complex factors arising (particularly teacher behaviours and pedagogy) are rarely accounted for; fair comparisons using test scores alone are almost impossible. However, ICT itself can play an important role in shaping the mathematical activity.

A study in the USA involving 42 pupils taught by the same teacher sought to discover the problem-solving techniques used by pupils within a mathematics lesson (Arthurs *et al.*, 1999). Among the resources provided to some of the pupils was a meta-cognitive software package designed to support inductive reasoning. It was found that those pupils who had access to extra resources including the meta-cognitive software considered more than one way to approach a problem, so there was some evidence that these tools were affecting pupils' practices.

Christmann *et al.* (1997) conducted a meta-analysis[12] in the USA, which compared the academic achievement of pupils from grades 6–12 (the equivalent of years 7 to upper sixth form in the UK) who received either traditional instruction or traditional instruction supplemented with computer-assisted instruction across eight areas of the curriculum. On average, pupils receiving traditional instruction supplemented with computer-assisted instruction attained higher academic achievement than did 58.2% of those only receiving traditional instruction.

[10] Logo is a programming language designed as a tool for learning, most commonly used in mathematics and science.

[11] Boolean logic symbolically represents relationships between entities. There are five Boolean operators: AND, OR, NOT, GREATER THAN and LESS THAN.

[12] Meta-analysis is the statistical analysis of a large set of analysis results from previous individual studies, with a view to integrating the findings.

In England, an analysis carried out by Becta (2001b) found better results at Key Stage 3 in schools using ICT to support mathematics and science compared to schools where it was not being used to the same degree. Higher GCSE results were also found in schools that made more use of ICT across the curriculum. Schools with good ICT resources, good ICT teaching and good use of the resources (based on inspectors' assessments) showed better attainment at Key Stages 3 and 4 compared to schools where these aspects were poor. A consistent difference was found in attainment between those schools with good ICT resources and those with poor ICT resources. Again, this research focused only on correlations (between schools' ICT resourcing, ICT use and exam results), rather than causal relationships.

In view of the central position of mathematics within many integrated learning systems (ILS), some ILS research projects have also considered the role of these systems in increasing attainment or understanding in mathematics. The UK evaluation discussed previously (Detheridge, 1994) found more evidence of attainment gains in numeracy than literacy, although this was to a limited extent. Among other ILS research projects is an early nationwide study of US grade 5–8 (UK year 6–9) classes (Becker, 1990) by the same researcher who went on to write widely on integrated learning systems (Becker, 1992a) and then to head the Teaching, Learning and Computing programme. The researchers found that there was little evidence of ILS impact on student achievement. Where differences were found between the achievements of ILS users and comparible non-users, Becker concluded they were too small to have any educational significance.

A five-year longitudinal study of the teaching and learning of mathematics, the Leverhulme Numeracy and Research Programme at King's College London, involved two groups of 1,600 pupils in 75 classes. Although a recent paper from the project (Brown *et al.*, 2001) does not address the use of ICT overtly, there are key understandings included about the pedagogies of effective teachers, which relate to the use of a range of tools which could include ICT.

Transfer of skills from mathematics-based software to other contexts has been a concern of other researchers, in addition to those concentrating on integrated learning systems. Researchers in Hong Kong (Au and Leung, 1991) considered the extent to which skills gained in programming with Logo could be transferred to new contexts. They reported that the key factor was the way in which Logo was taught; if approached through a process-based methodology, it was more likely that the skills gained would be transferable to other contexts.

Recent research includes a Finnish project which looked at the learning styles that were found to be most effective in a Logo lesson (Suomalo and Alajaaski, 2002). They found that the most effective learning styles were those that were related to discovery methods rather than teacher direction.

An Australian study (Ainge, 1996) with a small sample size examined the use of virtual reality for teaching geometry within Aboriginal communities. Evidence was found of better shape recognition in the group using the virtual reality tool than in the small control group, although there was no apparent improvement in shape visualisation. Ease of use of the virtual reality tool and increased pupil engagement were noted informally.

Particular themes in the literature for attainment in mathematics

As has been shown above, the effect of ICT on pupils' attainment in mathematics is most evident regarding uses of ICT which link to specific mathematical skills and processes, often revealed in smaller focused studies. Examples of these smaller-scale studies which deal with particular areas of mathematics are discussed below.

Logo

Since the early work of Papert (1980) was published, there have been a large number of studies investigating pupils using Logo, and many claims have been made for its contributions to learning. Clements (2000 pp. 28–29) summarises research on Logo as follows:

'Used appropriately, computer programming has been shown to help pupils to:

- develop higher levels of mathematical, especially geometric, thinking
- learn geometric concepts and skills, including two-dimensional figures, angles, symmetry, congruence, and geometric motions, although teacher guidance is important
- gain "entry" to the use of the powerful tool of algebra
- develop concepts of ratio and proportion
- form more generalised and abstract views of mathematical objects

- develop problem-solving abilities, especially particular skills (eg problem decomposition, systematic trial and error) and higher-level meta-cognitive abilities
- enhance the social interaction patterns.'

Hoyles *et al.* (1991) analysed the processes whereby pairs of secondary school pupils (12- to 13-year-olds) made mathematical generalisations in three environments: using Logo, a spreadsheet, and paper and pencil. The main findings were: 'In all three environments inter-pupil discussion served a scaffolding role in the step towards a mathematical generalisation... Formalisation took on a significant role in the computer environments in contrast to the paper-and-pencil environment'. (Ibid., p. 23.)

Hoyles and Noss (1992) attempted to map out some relationships between pedagogy and pupil behaviour in a Logo-based microworld[13] constructed around the notions of ratio and proportion, showing that the intervention of the teacher for many pupils was crucial to the success of their procedures.

Another study by Johnson-Gentile *et al.* (1994) compared two groups: an experimental group using especially designed Logo computer environments, and a control group using manipulatives and paper and pencil (manipulatives are objects and shapes, such as jigsaw puzzles, building blocks and paper which are used in mathematical tasks, such as cutting a large paper square into a smaller set of shapes). Interviews revealed that the experimental group performed at a higher level of geometric thinking than the control group. There was support for the notion that the Logo-based version enhanced students' ability to construct higher-levels of conceptualisations of motion geometry. However, these and other similar studies involved pupils using Logo outside of the normal curriculum. How Logo might complement other mathematical activities was not researched.

More recently, Johnson (2000), in the context of programming, observed that 'the position (opinion) that the programming environments themselves, e.g. Logo microworlds, would become the school mathematics curriculum has clearly failed to gain the support of the educational system.' (Ibid., p. 201.)

Yusuf (1994) investigated the effects of Logo-based instruction on the cognition of the four fundamental concepts in the geometry curriculum, and explored the possibility of integrating the Logo programming language in the geometry curriculum. His results showed that pupils in the experimental group had a deeper conceptualisation of fundamental concepts in geometry. He concluded that the experimental group performed better because of the Logo programming exercises and Logo tutorials. Logo-based instruction was applied in the teaching of basic geometric concepts (points, rays, lines and line segments). The experimental group produced significantly better results in terms of both pupils' achievement and attitudes (Yusuf, 1995).

Programming

In spite of the Logo movement, which involved many researchers and developers, more recent evidence has shown that its use is declining in UK schools, partly with the advent of the IT/ICT curriculum and the growth in the communications aspects of university courses at the expense of the core programming elements. Cope and Walsh (1990) concluded that early claims about the development of high-level thinking skills had not yet been supported, although 10 years later, Johnson (2000) observed that 'The contribution of programming in the learning of school mathematics has been demonstrated in numerous project and research settings. However, it would appear that this activity has failed to permeate the system on any large and systemic scale…Without a substantial commitment to supporting the innovation [of discrete mathematics] we may well be advised to give up.' (Ibid., p. 201.)

Quadratic functions

One of the earliest applications of ICT in mathematics teaching was in solving mathematical equations (see for example Suppes (1968)). More recently there has been research into the use of mathematics software to enable pupils to construct and analyse quadratic functions. Dreyfus and Halevi (1991) explored a computer-based open learning environment dealing with families of quadratic functions, which provided a framework for exploring questions. The environment proved to be a sophisticated learning aid with the potential for challenging even relatively weak pupils to deal in depth with difficult topics. They

[13] A 'microworld' is a term coined by the MIT Media Lab Learning and Common Sense Group. It means a tiny world inside which a pupil can explore alternatives, test hypotheses, and discover facts. It differs from a simulation in that the student is encouraged to think about it as a 'real' world.

observed that the support and guidance of the teacher in the classroom is crucial for pupils to be successfully challenged, which supports many other studies showing that the pedagogy of the teacher has a major influence on the effectiveness of ICT on pupils' attainment.

Godwin and Beswetherick (2002) reported on research being developed within the 'Teaching and Learning' strand of the Economic and Social Research Council project, InterActive Education: Learning in the Information Age. The research focused on the learning and understanding of quadratic functions using a graphical software package, and included a discussion of how the structuring of the activities influences the nature of the learning environment, and how it might influence pupils' exploration of mathematical concepts. There is a strong link between the ability to solve quadratic functions and the ability to interpret graphs – an area where many ICT-based packages have made a positive contribution.

Graphs

A major feature of ICT interfaces has been their ability to display graphical images, and the way in which complex relationships can be represented through interactive graphs on the screen (Laurillard, 1978; Mellar *et al.*, 1994). This feature of ICT displays has been shown to enhance pupils' understanding of scientific relationships as well as mathematical ones.

Friedler and McFarlane (1997) examined data logging using portable computers as part of an investigative approach to science, but their findings have implications for mathematics. This activity was embedded in the normal science curriculum and delivered by the usual class teachers. Working with control and experimental classes of 14- and 16-year-olds, the results of pre- and post-test comparisons suggest that the use of data logging can have an impact on graphing skills at age 14, which is not necessarily repeatable at 16.

Hennessy (2000) evaluated the use of palmtops with 23 year 9 pupils and 25 year 8 pupils. The main gains were in the motivation of the pupils. The learning gains were greatest in the area of determining intercept, interpolation and finding range from a graph.

Another study of pupils' graphing abilities conducted by Hudson (1997) investigated graphs of relationships (distance–time) using a multimedia package. Rich interaction was observed between all group members. The classroom trials showed that the ICT environment had a significant impact on pupils' interactions and supported and sustained collaborative learning.

This work was supported by a later study which showed that using a computer can provide the necessary input during the learning session to allow the means for gradual refinement of graphing skills (Sivasubramaniam, 2000). His results support the earlier work of Smith *et al.* (1993), who claimed that the purpose of teaching should not simply be to exchange misconceptions for expert concepts but the aim should be to provide the means for complex and gradual processes of conceptual change to take place.

Computer algebra systems

Computer algebra systems have also been a recent focus of attention. This software can do most of the manipulation of numbers, symbols, vectors and matrices required in secondary school and beyond. Used imaginatively, computer algebra systems may enable pupils to explore algebra and to learn new concepts, just as younger children can explore numerical ideas with a calculator. Several graphic calculators now incorporate computer algebra systems.

Herget *et al.* (2000) claim that mathematics education will not become simpler as a result of computer algebra systems. 'A consequence of the new tools is that mathematics becomes more useable and probably more demanding, but definitely not simpler.' (Ibid., p. 11.)

Monaghan (2001), in a series of articles, claims that the conscious use of the algebraic capabilities of calculators may help pupils to focus on suitable approaches to a particular task, whereas paper-and-pencil schemes focus on rules of transformation. Paper-and-pencil and calculator practices can be thought of as complementary in teaching, rather than opposed. Teachers and pupils talk about the tasks and techniques when using the calculator, and so develop a specific language which they can then use to consider the consistency and the limits of those techniques. Techniques without schemes are ineffective since they are not likely to evolve and cannot produce knowledge.

Gardiner (2001), however, is concerned about the role of prior experience with suitable mental and written methods: how much depends on practice, how much practice is needed, and how important is technical fluency?

In one of the few studies to report specific gains, Shaw *et al.* (1997) used computer algebra systems in an intermediate algebra course. Three groups were compared:

'college', who did not need a developmental programme; 'traditional', who did a traditional developmental programme; and 'technology', who did a course using the computer algebra systems, but with no change in the format or objectives of the course. No indication is given of the way in which the software was used. The results of mean grades in an introductory statistics course showed that the pupils using the software performed better than the other two groups. The researchers checked on completion rates for the two developmental groups, and also the composition of the groups in terms of ethnicity and gender, and found no differences.

Calculators

Jones and Tanner (1997) reported on a study to explore the effects of the use of calculators on the basic arithmetical skills of Welsh secondary school pupils. Departmental policies on the use of calculators varied greatly. The researchers found three models of use: 'available', 'discouraged' and 'restricted'. A test of basic skills given to all year 8 pupils in 11 schools showed that pupils who reported that they used calculators did better than pupils who did not, although there were no significant differences between pupils' performance related to the models of use, and no significant differences in the results related to the gender of the pupils. Compared with standards from the 1970s, pupils' ability with fractions had decreased, but scores in number and decimal work were on a par. The results 'suggest that calculators were not being best used to improve pupils' learning.' (Ibid., p. 34.)

The effects of ICT on mathematics attainment – conclusions

The research evidence described in this section shows that ICT can have positive effects on pupils' learning of different concepts and skills in mathematics at both primary and secondary levels. These effects are most evident through measures which take account of the specific skills and tasks involved. For example, these skills might involve constructing mathematical models, hypothesising relationships, interpreting graphs, and learning concepts of ratio and proportion. Large-scale studies which have included special measures to assess the effects of new technologies have produced more positive results than those where standard national tests have been used, which are not specifically designed to measure new ways of reasoning, hypothesising or expressing knowledge.

The evidence is not so clear regarding whether ICT can have a larger effect on pupils' attainment than other teaching methods, although there are examples of ICT contributing to the learning of specific skills and concepts which would be difficult to teach so effectively using other methods. The evidence also shows that learning and attainment is closely related to the learning context, the role of the teacher and the regular integrated use of the ICT application in the curriculum.

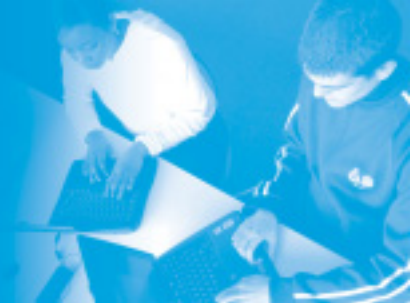
Science

During the early years of ICT use, science classes were the site of various innovations. Modelling was used to build an understanding of pupils' misconceptions (Brna, 1990, 1991), and has been shown to enhance pupils' cognitive skills (Taylor *et al.*, 1997). ICT has been used as a facilitator of learning (Gilbert and Watts, 1983; Dreyfus et al., 1998; Cookson, 2001) rather than as a central component of the teaching and learning in the classroom.

Some recent studies have suggested that high levels of ICT use may be linked to improved attainment in science. In an analysis of inspection data from the Office for Standards in Education (Ofsted) from 1998–99 based on 2,500 primary schools (Becta, 2001a), a significant statistical correlation was found between the grade allocated by inspectors to a school's level of ICT resources and attainment in science at Key Stage 2. The results still hold when allowance is made for socio-economic factors and pupils' prior level of attainment.

In a similar analysis of Ofsted inspection data from 1998, 1999 and 2000 and attainment at Key Stages 3 and 4 based on results from 409 secondary schools (Becta, 2001b), a consistent positive difference was found in science attainment between those schools with good levels of ICT resources and those with poor levels of ICT resources. There was not the same consistency between other levels of resources.

In a further study, the relationship between good use of ICT and standards of achievement was analysed from Ofsted inspection reports from 2,582 primary schools (Becta, 2003). Ofsted inspection judgements were compared with achievements of schools at Key Stage 2. The report concludes that there are strong links between good use of ICT resources and attainment in science as well as other subjects. However, the studies described above did not analyse causal relationships, and other factors such as good leadership and general quality of



teaching may be more important than ICT use. However, the results suggest that the reasons for these differences in attainment are worth investigating further.

A meta-analysis by Christmann et al. (1997) focused on secondary education using previous research that met pre-determined criteria. The meta-analysis, which combined a minimum of 20 pupils in experimental and control groups, indicated that pupils receiving traditional instruction supplemented with computer-assisted instruction attained higher academic achievement than did those only receiving traditional instruction, and that the effects on achievement were greater in science than in other subjects.

In the ImpaCT2 project (Harrison *et al.*, 2002), statistically significant positive associations between the level of ICT use and pupils' attainment were found for science at both Key Stages 3 and 4, and the enhanced performance approximated to an increase in performance of 0.56 of a GCSE grade in science. The study focused on the overall frequency of pupils' use of ICT in determining its effects on their attainment, but no distinction was made for different types of ICT use or quality of ICT use.

Other smaller studies have reported no clear differences in attainment or achievement in science between classes making more use of ICT and those using less (Alspaugh, 1999; Baggott La Velle *et al.*, 2003). Other studies designed to compare the use of ICT with more traditional approaches for teaching specific topics have found no difference in learning gains (for example Bezanilla and Ogborn, 1992; Crosier *et al.*, 2000). Some of these studies were designed to evaluate specific pieces of software (for example Crosier *et al.*, 2000) and resulted in improvements to the software.

Various studies have reported pupils' and teachers' perceptions that learning is improved through using ICT, but have not provided evidence of any actual measurements of learning gains (Kiboss, 2000; Wilson, 2001; Smith, 2002; Trumper and Gelbman, 2002). Other writers have tended to concentrate on the practical implementation issues rather than considering the evidence for learning gains (Bell *et al.*, 1998; Bell and Bell, 2003). Other writers have focused on comparing learning gains for different approaches to using the software rather than comparing the ICT-based intervention with conventional approaches (Lajoie *et al.*, 2001; Yu, 2001).

In some cases, ICT has hindered rather than promoted learning. Physics classes using a software tool took longer to learn how to use the software than they would have done to achieve the learning outcomes without it (Davelsbergh *et al.*, 2000). In a study of the use of email to develop science investigation skills in six rural schools in England (Jarvis *et al.*, 1997), teachers felt that the enthusiasm of pupils increased, but there were no real indications that the use of email enhanced learning in science. At the same time the researchers also found that the time spent communicating by email detracted from learning science although it did help pupils develop their ICT skills.

In the first ImpacT project (Watson, 1993), the range of methods used showed that it was possible to measure pupils' attainment resulting from the use of ICT, but that the research methods need to be closely matched to the nature of the learning taking place. For example, in one of the mini-studies into the effects of ICT on pupils' ability to analyse scientific data, the assessment methods included pre- and post- tests which required pupils to group sets of data according to specific criteria, using Boolean logical operators. The results showed that pupils who had used the computer database package were able to use more advanced data-analysis skills using Boolean logical operators than those used by the pupils who had not used data-handling software (Nikolopoulou and Cox, 1999).

There is evidence of the contribution of computer-based modelling to pupils' learning in science. Work in physics was reviewed in an earlier study by Niedderer *et al.*. (1991), who concluded that computer-aided modelling at the upper-secondary level (pupils aged 16–19) does work in normal classroom settings, and provides more complex and realistic examples of a larger number of phenomena. He found that it shifted the focus of instruction from mathematical to conceptual examinations of physical phenomena, and supported teaching strategies that put weight on the active involvement of pupils.

Work done by Webb (1992) measuring the strategies of primary pupils building qualitative models using software showed that they learnt logical strategies for categorising scientific processes and could construct relevant and reliable models.

Three 10th-grade classes in Israel (equivalent to year 11 in the UK) were the subjects of a more recent research

project (Barnea and Dori, 1999), which reported considerable gains in the understanding of molecular geometry and bonding by pupils who were given access to three-dimensional modelling software.

A significant use of ICT in science education is the incorporation of specific simulations into the existing curriculum. Huppert *et al.* (1998) conducted an experimental study of the effect of computer simulations on pupils' ability to apply their knowledge of the growth curve of micro-organisms. The computer simulations were integrated as short episodes in the existing biology curriculum. The post-test results on academic achievement indicated that pupils in the experimental group achieved significantly higher mean scores than the control group. The suggestion here is that pupils are performing at higher cognitive levels for two reasons. First, they are able to carry out more investigations more quickly and focus on their analysis and hypothesising. Secondly, collaboration enabled pupils to exchange ideas and compare results.

Studies have shown the value of simulations for enabling visualisation and hence helping pupils to solve problems. Monaghan and Clement (1999) analysed think-aloud interview protocols from three pupils who interacted with a relative motion computer simulation presented in a predict–observe–explain format. They found that interaction with a computer simulation online can facilitate a pupil's appropriate mental simulations offline in related target problems.

Dori and Barak (2001) conducted an experimental study using a new teaching method that combines two types of three-dimensional molecular model: physical (plastic) and virtual (computerised). The research, based on 276 pupils from nine high schools in Israel, showed that pupils in the experimental group gained a better understanding of the concept and were more capable of defining and implementing new concepts, such as isomerism and functional groups. They were better capable of mentally traversing across four levels of understanding in chemistry: symbol, macroscopic, microscopic and process. Pupils in the experimental group were more capable of applying transformation from two-dimensional representations of molecules, provided by either a symbolic or a structural formula, to three-dimensional representations, to a drawing of a model, and of applying the reverse transformation. An interesting finding was that the pupils of a low academic level in the experimental group expressed their explanation graphically.

Trindade *et al.* (2002) in a study of 20 first-year university students found indications that three-dimensional virtual environments may help pupils with high spatial aptitude to acquire better conceptual understandings of physical and chemical processes such as phases of matter, phase transitions and atomic orbitals. However, only some parameters (interactivity, navigation and three-dimensional perception) were shown to be relevant, and only for some topics.

Henderson *et al*. (2000) investigated whether young pupils (seven years old) learnt the information and concepts embedded in a computer microworld simulation in science, as opposed to treating it merely as a game to be played. They found changes in cognitive outcomes and processes after learning with the software which was integrated with a thematic curriculum in a classroom over a period of six weeks. The pupils used the software for 45 minutes each day, working in pairs, and the results indicated improvement in their thinking skills and strategies, from basic recall to higher level skills such as classification and inference, and their use of scientific language.

Much research in science education demonstrates that children, as a result of their experiences in everyday life, develop their own naive theories or misconceptions, and these are very resistant to teaching (Gilbert and Watts, 1983; Driver *et al.*, 1985). Some interventions involving simulations have been designed specifically to address specific alternative conceptions. Tao and Gunstone (1999) investigated the use of computer simulations integrated into 10 weeks of physics instruction of a class in a Melbourne high school. The simulations specifically developed to confront pupils' alternative conceptions in mechanics. During the process, pupils complemented and built on each other's ideas and incrementally reached shared understandings. Pupils' conversational interactions showed that this led to conceptual change.

Jimoyiannis and Komis (2001) extended theoretical instruction with the use of simulations in physics teaching aimed to help pupils' transformation of alternative conceptions. In this study, two groups (control and experimental) of 90 15- to 16-year-old pupils were studied to determine the role of computer simulations in the development of functional understanding of the concepts of velocity and acceleration in projectile motions. Both groups received traditional classroom

instruction on these topics; the experimental group used computer simulations also. The results showed that pupils working with simulations exhibited significantly higher scores in the research tasks.

In summary, experimental studies show that the integration of simulations within existing curricula does improve pupils' understanding at both primary and secondary levels, possibly through the following mechanisms:

- providing experiences producing dissonance/cognitive conflict
- creating frameworks for visualisation
- providing a focus for discussion, comparing results and exchanging ideas.

The simulations can be integrated into the existing curriculum and combined with laboratory experiments, theoretical instruction and, in some cases, exploration of physical models. Where the design or selection of the software focuses on pupils' alternative conceptions, its use may be particularly beneficial.

Barton (1997) reviewed some research on data logging. Three different studies supported the hypothesis that real-time graphing removes drudgery and saves time, and this was also supported by small-scale studies by Barton himself.

Another small-scale study by Barton (1997) based on exploring relationships between electrical power and current in a resistor found no benefit of real-time graphing over delayed presentation. Other studies have shown no difference in pupils' understanding using traditional manual data recording and automated data collecting (Striley *et al.*, 1990).

Linn and Hsi (2000) found that pupils were much better at interpreting the findings of their experiments when they used real-time data collection than when they constructed their own graphs. Pupils' understanding of time-dependent graphs was enhanced even in topics that they had not studied before. For example, pupils were better at interpreting graphs of speed over time after studying cooling over time when they used real-time data collection. No similar benefits arose when pupils used conventional techniques for graphing their data (Linn and Hsi, 2000).

Some experimental studies have shown that carefully designed software can develop specific scientific skills. Taylor *et al.* (1997) assessed decision making, and evaluated the impact of using computer-based laboratories on the development of these skills among 277 ninth-grade pupils in the USA (equivalent to year 10 in the UK) in one high school. The pupils took part in either a computer or equivalent paper-and-pencil role-playing exercise requiring them to evaluate the possible eruption of a volcano. Pupils who used the computer exercise made more consistent decisions than those who used the traditional paper-and-pencil exercise.

There is limited research into pupils' learning experiences while creating their own educational multimedia applications for science topics. Kafai *et al.* (1997) present and discuss the results of a project in which seven teams of elementary school pupils (10–12 years old) were involved in designing and implementing interactive multimedia resources in astronomy for younger children. Pupils improved significantly in both their understanding of science and their programming skills over the 46-hour period, but there was no control group with which to compare achievement.

The web has often been seen as a useful source of extended or more appropriate data (Hawkey, 2001), although web-searching skills should not be taken for granted (Lazonder 2001).

Hollow (2000) presented case studies of pupils' research projects, and argued that they provided a valuable opportunity for secondary school pupils to experience many of the joys and frustrations that make up the intellectual challenge of science.

However, the benefits of these types of experience are difficult or even impossible to quantify or describe in terms of pupils' attainment or achievement in any measurable way.

Stork et al. (1999) reported on the KidSat project, involving collaboration among middle school, high school and university pupils with scientists, engineers, teachers and educational theorists to create a programme supported by the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF) and the Johnson Space Center, which tied real-time scientific exploration and discovery to learning in the classroom. In this project, the outcomes of the standardised test results indicated that there were no detectable differences between the KidSat group and the comparison group in growth in aptitude and achievement, but the teachers at all five schools and the

evaluation team observed substantial improvement in pupils with regard to their in-class performance, motivation and interest in earth and space exploration.

McKinnon and Nolan (2000) studied distinction courses for secondary-level gifted and talented pupils, and described in particular a course on cosmology that employed an interactive design model and an extensive communication system in which the concept of 'learning community' largely replaced the concept of 'teacher'. Achievements in this context were very much individual and are documented through vignettes about successful pupils and how their projects developed, and about how they were supported to achieve work of a very high standard. For example, a 17-year-old pupil demonstrated the ability to interpret the observations currently being made by researchers at the leading edge of observational astronomy.

Digital video editing has only fairly recently been available to schools as a learning opportunity, and articles tend to focus on the technology and its opportunities rather than providing evidence of its effects on attainment or achievement (for example see Michel *et al.*, 1999). Reid (2002), in an evaluation of a pilot study of digital video in 50 schools from across the UK, reported that teachers commented that filming 'forces', and editing this into a piece of film, helped pupils assimilate scientific concepts more effectively, quickly and substantially than would have been achieved with handouts or textbooks.

The Computer as Learning Partner (CLP) collaboration at the University of California (Linn and Hsi, 2000) was a longitudinal study that developed a curriculum and associated pedagogy for a semester-long science course that aimed to integrate appropriate use of ICT. It is one of very few examples of developments where the use of ICT was planned into a new curriculum, and the process and outcomes were researched. The associated classroom research studies used pre-tests and post-tests to measure specific aspects of scientific understanding, problem-solving and inquiry skills. As the curriculum and pedagogy developed, its effectiveness was measured by comparing the performance of two groups of pupils, one using the current version of the curriculum and the other using the previous version. The researchers concluded that there were substantial improvements in understanding, problem-solving and inquiry skills. In a study such as this, where the use of ICT is not only deeply integrated into the curriculum, but the curriculum is being redesigned based on research into how children learn, it is not possible to attribute improvements in learning solely to the use of ICT, because it is the whole learning environment that enables these improvements. In this curriculum, ICT enables pupils to plan their work and consult checklists to track their progress, collect data and display results in real time, use simulations, make predictions online and compare these with the outcomes of their experiments. The design of the CLP curriculum focused on guiding the process of connecting, linking and reorganising, so that pupils could concentrate on thinking about their experiences in productive ways.

Other long-term studies of the implementation of technology in secondary school science classrooms are those associated with the Canadian Technology-Enhanced Secondary Science Instruction (TESSI) project (Pedretti *et al.*, 1998; Mayer-Smith *et al.*, 2000). The TESSI project started in 1992 and was designed to examine the outcomes of combining the elements of successful science instruction with the application of state-of -the-art technology. The project was regarded as successful in that participation rates in science increased because pupils found the approach more interesting than traditional science classes, but the attainment of TESSI pupils as measured by provincial examination scores was at, or slightly below, that of other pupils. Pedretti *et al.* (1998) reported that pupils were able to offer explicit examples of how technology had had an impact on their learning. For example, 64% of the pupils interviewed voluntarily explained how they valued and enjoyed taking tests on computers. They spoke about how computer assessment could actually promote remediation and understanding. While three pupils did focus on the benefits of simulations, the vast majority spoke about laboratories and technology as complementary, both playing a role in enhancing learning. TESSI pupils were also able to discuss meta-learning issues: they spoke about learning to learn, and learning responsibility, independence, self-reliance and problem solving. Mayer-Smith *et al.* (2000) reported from the TESSI project that effective pedagogical practices with technology can promote a more equal environment for pupils of both sexes, where girls and boys participate and perform equally well.

Some research has examined whether ICT-based simulations can provide a substitute for experiences in a

museum or learning centre. For example, Baxter and Preece (2000) in a study of 48 pupils in years 5 and 6 (9- and 10-year-olds) found that learning was equally effective when pupils were taught with the aid of the computer planetarium compared with a dome planetarium. In this case, the use of ICT has not revealed any increased achievement, but it does provide the opportunity for pupils who may not be able to travel to such a facility to have similar learning opportunities.

The effects of ICT on science attainment – conclusions

It is clear from the evidence that ICT has had a positive effect on many areas of attainment in science. Research into the area of science education has included investigation of pupils' misconceptions and what teaching methods can be used in response for over 40 years, so there is a large body of knowledge in this area. This has enabled developers and researchers to produce educational software which addresses these learning difficulties. What is also apparent from the evidence is that, unlike in English, the types of ICT use are much more closely related to specific concepts and skills and tend to be more subject specific than, for example, the use of word processing.

Because of the nature of many of the ICT technologies and resources used in science, it is also more straightforward to devise instruments to measure the effects on attainment. Many researchers have devised measures which relate to the specific interactions and tasks promoted by a simulation or a modelling environment, and which are therefore able to measure more reliably the effects of ICT on attainment. There is evidence of a positive effect of specific uses of ICT on pupils at all key stages, which is related to their conceptual development in science and the types of learning environments available to them. It is still the case that ICT is not used extensively in the science curriculum, but where it has been appropriately integrated there is evidence that it has enhanced the learning of pupils.

ICT in ICT subject lessons

Although few national studies have been conducted in the UK to investigate the effects of a range of ICT resources on attainment, there are many research studies into specific aspects of ICT, which have produced useful results.

A recent study of over 100 IT co-ordinators in England, by Preston *et al.* (2000), found that less than 10% of the ICT teachers were using anything other than word processing more frequently than once a month, despite the broader and deeper requirements of the ICT curriculum. The ICT curriculum covers using simulations, building computer-based models, analysing data, measuring and controlling experiments and communicating information.

As previously discussed, there is much evidence to show that simulations can contribute to learners' understanding of science. For the ICT curriculum, some of the concepts and processes are similar to those in science, that is, hypothesising relationships, exploring models of real and imaginary situations and evaluating the effectiveness of computer simulations. Simulations can present different representations on the screen compared with those provided by more traditional resources.

Research into pupils' understanding of different representations has shown that the learner needs to understand the metaphors and symbolisms (Mellar *et al.*, 1994). New technologies have changed the representation and codifying of knowledge, and this has affected learners' mental models, showing that learners develop new ways of reasoning and hypothesising their own and new knowledge.

How different these ways are from previous methods of reasoning and hypothesising is influenced by the nature of the representation system and the ability of the learner to interpret new images and new literacies. Research into this area ranges from the artificial intelligence research into the interpretation of diagrammatic representations (Cheng *et al.*, 2001) to research into learner's causal reasoning using modelling environments (Bliss, 1994). All the evidence from 20 years of research in this field points to a fundamental change in the representations and therefore boundaries of knowledge within a particular knowledge domain.

Studies of pupils' abilities to build models using different modelling or framework software have shown that learners can interpret more complex simulations of a system than they can model from scratch. The building and evaluating of models enables learners to challenge their own ideas about topics, hypothesise the effects of adding new variables and develop models to extend their understanding (Mellar *et al.*, 1994). Different framework software can challenge the learner to investigate the same processes but may provide totally different representations. For example, an investigation of energy

consumption in the home could be carried out using a common spreadsheet application or an educational modelling environment (Cox and Webb, 1994). These two software environments offer completely different representations of the same problem because of the design of the modelling framework. In the case of the spreadsheet application, the learner needs to understand the relationship between mathematical equations and tabular means of presenting and inserting these. In the case of the educational modelling environment, the learner needs to learn a new modelling syntax based on natural language, and learn how this can be used in conjunction with icons and images on the screen (Cox, 2000).

Another key area for the teaching of ICT is data handling, which is also relevant to many other areas of the curriculum. An early study was made of 13- to 14-year-old pupils' performance on two parallel logical reasoning tasks related to database searches (Bezanilla and Ogborn, 1992). Pupils were given tasks designed to assess their understanding of binary logical sentences. Common errors such as confusion of AND and OR were identified. The misunderstandings were identified through the use of questionnaires. The actual test questions were found to be quite hard to understand and were dissimilar to the ICT-based tasks; this, therefore, may have been one of the reasons for the lack of improvement.

Another study conducted by Nikolopoulou and Cox (1997) investigated secondary school pupils' ability to sort and group chemical data by common chemical characteristics. They tested two pairs of experimental and control classes, who were being taught how to analyse characteristics of chemical data. The control classes were taught the analysis procedures using paper-based records and lists of data. The experimental classes used a database package to learn about data queries and the analysis of specific characteristics. All classes were given paper-based pre- and post-tests in which they had to sort unfamiliar chemical data. The results showed that the experimental classes could use the Boolean logical operators AND and OR at the age of 13, and could conduct combined operations, whereas only a few of the control group pupils could reach this level of attainment.

Another interesting finding was that the group using ICT could sort data which had a specific unique characteristic, for example melt in water, but they could not sort data in ascending or descending order when it involved the use of numerical characteristics. This skill requires pupils to understand the Boolean operators GREATER THAN and LESS THAN, which was shown by the research of Bezanilla and Ogborn (1992) to be more difficult.

The effects of ICT on ICT attainment – conclusions

The evidence from the literature has shown that innovative and challenging uses of ICT can improve pupils' data-handling skills, and their ability to construct complex models.

Clearly the subject of ICT is a special case because it is essential that both practical skills and theoretical knowledge are developed. The research shows that if teachers provide opportunities for pupils to carry out in-depth investigations with appropriate modelling environments then they can reach higher levels of abstraction and competency in the field of ICT.

Effects of ICT on modern foreign languages

Research into modern foreign languages education includes the areas of linguistics and the effects of new technologies. As with the teaching of English, much of the success reported in the literature is linked to particular sub-skills of language learning such as word recognition and vocabulary building (Pawling, 1999) rather than more holistic gains. The most consistent evidence is where the instruments used during research have measured specific skills closely related to those used through the ICT application. Some researchers have also discussed the role of ICT in modern foreign languages, but not conducted significant research on the effects on pupils' attainment (Leh, 1999; Tzortzidou and Hassapis, 2001).

A French ethnographic[14] study by Carel (1999) found that a more pragmatic awareness could be developed in virtual contact situations.

Discussing the requirements for initial teacher education, the PGCE lecturers at one university saw a place for ICT within modern foreign languages, but only within a repertoire of alternative resources (Barnes and Murray, 1999).

Although it is likely that more studies on the effects of ICT in modern foreign languages exist, particular in overseas

[14] Ethnography is a form of research which focuses on the sociology of meaning within a particular community. Members of the community are interviewed with a view to revealing the common cultural understandings related to a specific topic.

literature, it was beyond the scope of this study to investigate this further.

ICT in humanities

Overall there is less evidence from the literature about the effects of the use of ICT on attainment in humanities than for the other foundation subjects. However, there is a significant body of evidence to show how ICT can be used in both history and geography, especially at Key Stages 3 and 4 (for example Watson, 1993). This use of ICT includes role-playing games, simulations, databases and internet searches.

History

A number of researchers have considered the role of ICT in history teaching (Copeland, 1991; Wolfrum *et al.*, 2001). Observations by teachers of 20 high school classes in the USA (Copeland, 1991) suggested that the use of computer-based materials for historical enquiry could be very effective, but only where teachers were well prepared and understood exactly how to manage these resources.

A recent case study of 32 UK pupils working on a project linking the characters from a well know series of children's fantasy books with the historical murder of the princes in the tower reported that the use of ICT did enhance pupils' learning (Nichol *et al.* 2003). Outcomes were broadly the same as previous uses of similar but card-based activities, but the introduction of ICT was reported to have helped in two key ways, by improving pupils' overall understanding of the problem and their ability to see links between different aspects of it.

Data on the use of ICT for historical writing is much harder to come by, but an early social studies project in the USA (Thornburg and Pea, 1991) did consider this area. The researchers found evidence of improvement in pupils' abilities to organise argumentation in writing after using computers for this purpose, but further research showed that this improvement was not transferred to other contexts.

The results of a study investigating the use of computers in historical enquiry (Copeland, 1991) suggested that the use of computers might be beneficial to the success of enquiry teaching. Seven teachers, teaching 20 classes of secondary school pupils, were observed. Three of the teachers received training in the methods of enquiry teaching (that is, pupils learning through investigation); the other three taught in a traditional way. While the results of the study suggested that the support of computers may be beneficial to the success of enquiry teaching, they indicated that such support may not be sufficient in the absence of adequate preparation by teachers, because 'curriculum materials are not "teacher proof"' (Ibid., p. 452). Even so, it was found that the availability of computer programs enabled properly prepared teachers to teach in a way they would not teach otherwise.

Geography

The first ImpacT project (Watson, 1993), which measured the effects of ICT on attainment in geography, found improved achievement in some aspects of the subject at secondary level. There were no reported uses of ICT in geography among the primary schools involved. The actual integrated use of ICT in geography was, however, very patchy across the 2,300 pupils in the study. Most of the positive evidence was provided by the case studies. However, some of the results at the secondary level showed clear evidence of improved geographical skills among pupils who used software packages to study underdevelopment, indicators for development and the relationships between geographical indicators. The other packages used were three general-purpose packages to help in the preparation of GCSE course work. The highly positive results for the 14–16 age group indicated that 'the use of the software enhanced the process and depth of enquiry engaged by the pupils and extended their understanding of the complexity of relationships between indicators' (Ibid., p. 139.)

A more recent study showed that pupils who used multimedia learning environments in geography were observed having more interactions with each other and with the teacher than was the case without the use of ICT, but learning gains did not change (Smeets and Mooij, 1999).

A research study which focused on pupils' understanding of erosion and agriculture (Beishuizen, 1992) involved 38 16-year-olds in the Netherlands. Twenty were given a tutorial explanation and 18 worked with a computer simulation. Those using the simulation outperformed the others on both types of questions, coded by the researchers as 'reproduction' questions and 'transfer' questions. 'During the review the pupils suggested and also invented a lot of relationships between variables, which are part of the model behind the program...The post-test reveals that pupils in the exploration condition produce more arguments to explain their solutions to the transfer questions than the pupils in the explanation condition.' (Ibid., p. 113.)

The effects of ICT on the humanities – conclusions

There is evidence to show that the use of simulations can enhance pupils' reasoning and decision-making and enquiry skills, and that use of ICT can enhance pupils' understanding of specific historical and geographical topics such as erosion and agriculture. There is very little evidence of ICT being used or evaluated in primary schools for the teaching of history and geography, and clearly this is an area of the curriculum where more ICT use and research is needed.

Art and ICT

A number of case studies considering the role of ICT in art have been published, many of which are of high quality, although not research based in a traditional sense. Topics have included the potential of ICT for disabled pupils of art (Nicholls, 1997) and the potential of digital imaging (Shaikh and Abbott, 2003). Nicholls identified key areas where the use of graphic imaging could be particularly meaningful for disabled children. Focusing in particular on identity formation, he discussed in detail the benefits of ICT-based graphics for a range of different pupils. Shaikh and Abbott (2003) described a project based in primary schools in Bradford, which investigated the potential of digital imagery for helping pupils explore aspects of the built environment in which they live. Despite studies such as these, more research needs to be done in this area to substantiate the findings.

Business studies and ICT

Given that many schools are now combining the teaching of business studies with ICT, it is possible to measure the effects of ICT on pupils' attainment in business studies through GCSE grades. However, little research has been published in addition to this, and details are not given of performance in the European Computer Driving Licence tests. More research in this subject is needed.

Physical education and ICT

The use of ICT in the teaching of physical education is still at a very early stage of development, and this may be why research in this area is so limited. At present research is confined to a few case studies, and is not yet substantial enough to enable any generalised conclusions to be drawn. More attention was given to the use of ICT within physical education when this was a compulsory requirement within the curriculum, but some papers do indicate the potential within this area (for example, Cunningham *et al.*, 1998).

Cross-curricular findings

Many research studies of ICT and attainment provide evidence which is relevant across the curriculum. This includes data handling, the use of presentation software, the use of different hardware such as laptops, PDAs and electronic whiteboards, and the use of the internet for finding information.

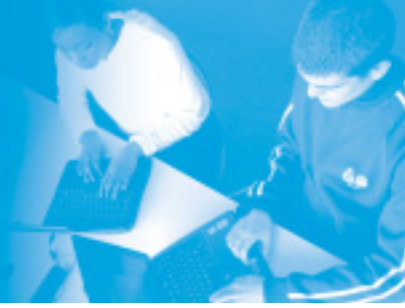
As discussed earlier (p. 26), a study of the performance of 13- to 14-year-old pupils on two parallel logical reasoning tasks (Bezanilla and Ogborn, 1992) is relevant to database searches and to many curriculum areas.

The study by Nikolopoulou and Cox (1997), also discussed earlier (p. 26), showed that pupils could sort large data sets at the ages of 12 and 13, but not if it required the use of more complex Boolean logic such as GREATER THAN or LESS THAN, or a combination of several logical sequences involving numbers. This research has important implications for pupils' ability to conduct focused and relevant searches on the internet.

The use of laptops was one area considered in the Digital Opportunities project in New Zealand (Boyd, 2002). This study reported a lack of impact resulting from the provision of laptops. It goes on to suggest two possible reasons for this: either that laptops just do not make a difference, or that such measurable differences are conditional on contextual features and are unrelated to the technology itself. These features may include the need for a different pedagogical approach, the need to create a pupil-centred environment and the necessity to fully integrate ICT into the curriculum. 'If this does not occur, and laptops are used within the traditional classroom environment simply as word processing and presentation devices, then it is unlikely that improvements in pupil achievement or changes to classroom environments will be reported.' (Ibid., p. 30.)

Special educational needs

ICT has changed the lives of many people with special educational needs, and has enabled them to participate to a greater extent in learning communities (Detheridge and Detheridge, 1997; Blamires, 1999; McKeown, 2000). The internet in particular offers as many possibilities for inclusive learning (Abbott and Cribb, 2001; Abbott, 2002a) as it does for unintended exclusion through lack of awareness of accessibility issues. Of course, this is not to suggest that the use of ICT by pupils with learning disabilities will necessarily show different outcomes or



highlight different aspects than use of ICT by the wider community would (Xin, 1999); indeed, recent US research has shown that the issues for the learning disabled are essentially the same (Brown-Chidsey *et al.*, 2001). More recently, lessons learnt from this area have been shared with the wider linguistics community (Abbott, 2002b) so that these developments can be placed in an appropriately wider context.

Much has been made in the educational press of the potential of ICT for supporting gifted and talented pupils, but research in this area is not common (McKinnon and Nolan, 2000).

Section 3 Factors and issues relating to ICT and attainment

There are many factors which will affect the impact that ICT has on pupils' attainment, such as the design of the hardware and software, the accessibility and suitability of the resources, and most obviously how the technology is used. Two key issues are discussed in this section: motivation and gender. Further analysis of the available research regarding ICT and teacher pedagogy can be found in the companion to this publication (Cox and Webb, 2004).

The effects of ICT on pupils' attitudes and motivation

There have been many claims regarding the effects of ICT on pupils' motivation (for example DfE/KCL, 1993; Gardner *et al.*, 1993; Cox, 1997). Ever since the early days of using small microcomputers, there have been reports of pupils spending longer on tasks, increasing their commitment to learning, achieving more through the use of computers and of being enthusiastic about using computers in their lessons.

As discussed earlier, the use of word processing can lead to improvements in written composition skills and other literacy skills, but it is also clear from many research studies that providing pupils with the opportunity to improve their writing and presentation skills can lead to a greater involvement in and commitment to their learning.

Stradling *et al.* (1994) surveyed 563 primary and secondary school pupils who had used portable computers. The majority of the 118 project co-ordinators reported an improved attitude to school work and homework. They also reported a greater commitment to and time spent on pupils' school work, often due to the opportunity to improve the quality of their presentation.

Through the use of word processing, pupils who otherwise do poorly at writing and have little interest in this aspect of their work, improve their self esteem, their commitment and perseverance in learning tasks. In a study by Cox (1997) of 144 pupils, over 70% believed that ICT helped them to achieve a better quality of work.

Similar evidence for an increased commitment to learning was found by the first ImpacT project (Watson, 1993). Results from interviews with pupils and observations of them showed that their commitment to their work was enhanced by the use of ICT.

Studies conducted by Abbott (1997, 1998) have shown that pupils with special needs choose to spend many hours working on web page material to improve their quality of presentation, demonstrating an increased commitment to the learning task.

The studies referred to above concern pupils that have regular access to word-processing applications, with sufficient time to develop their written work. The same degree of motivation would not be generated among pupils with very limited access, where they have no time to reflect on what they have written and to improve it.

Further examples of pupils' motivation are provided by the studies on the use of integrated learning systems in a number of schools. A study was made of the use of two different integrated learning systems in selected classes in four primary schools and eight secondary schools (NCET, 1994). The researchers found that the pupils using the integrated learning systems showed an increased commitment and dedication to studying, shown by the higher levels of concentration when using the systems, with less non-task interactions taking place than with the pupils in the classes not using the integrated learning systems. Some of the primary pupils even booked extra sessions during their lunch break if they had missed any timetabled sessions. There was, however, evidence from this research that the attention span of the pupils on any one task started to decline after about 17 minutes, although if the activity was changed the attention span was then much longer. The researchers also reported that primary pupils found the activity very intensive and were quite tired afterwards, which suggests that the intensive concentration required is not sustainable for very long periods.

The more recent ImpaCT2 project also measured the motivation of pupils through 15 case studies (Comber *et al.*, 2002). Researchers found that 'not only was ICT perceived to encourage pupils to become more focused on the task, but it was also seen by some teachers to enhance both the performance and cognitive functioning of those who had hitherto been on the margins of classroom activity, or traditionally had performed poorly.' (Ibid., p. 9.)

Much of the evidence referred to in this section is based on data collected from teachers' and pupils' reports.

More detailed tests to assess motivation and attitude, following the approach of Gardner *et al.* (1993), would enhance the body of knowledge in this area and would provide more systematic evidence of the relationship between different types of ICT use, pupils' attitudes and long-term changes in behaviour and learning. There are several well established theories which have been used as the basis for measuring pupils' attitudes and motivation, which are discussed in the following section.

The effects of ICT on pupils' attitudes and motivation – conclusions

Many of the research studies claim that ICT can enhance the attitudes and motivation of the pupils. There are two different methods of measuring the attitudes and motivation of pupils which should be considered in relation to these claims.

The majority of research studies have based their claims about the positive effects on pupils' attitudes and motivation on observations of a change in pupils' behaviour and on pupils' own comments. From these types of observations it is reasonable to conclude that using ICT has had a positive effect on pupils' motivation, but it is difficult to factor out the influence of an innovative and stimulating teacher.

The other research approach is to use attitude tests combined with systematic recording of pupils' behaviour and their achievements with and without the use of ICT, and before and after a period of use. Some research using this approach has also been reported here, and has shown a positive effect of ICT use on pupils' attitudes to learning, studying and spending more time on tasks. There are several well established theories for the ways in which pupils' attitudes and motivation can be measured which could be used as the basis for further more extensive research in this area.

Gender and ICT

There has been considerable evidence published on gender differences in the use of ICT for learning (Shashaani, 1994; Woodrow, 1994; Spender, 1995). One report (Barnea and Dori, 1999) describes gender-based differences in aspects of model perception and verbal argumentation on the part of Israeli 10th-grade pupils (equivalent to year 11 in the UK) studying molecular chemistry. A second Israeli paper (Nachmias *et al.*, 2001) also found a considerable gender difference in ICT skills, with boys consistently more able in their use of applications. However there was no gender difference in the use of the internet for learning. The authors of this paper also identified what they see as a key need for the educational use of computers to be supported in the home.

One study (Crombie and Armstrong, 1999) argues for the establishment of all-female computer science classes following findings showing that girls received greater support from teachers in such settings.

In Israel, researchers investigating internet practices among all 384 pupils in one school (Nachmias *et al.*, 2000) found that gender was very significant as an indicator of different approaches: a greater number of boys used the internet and they used it more frequently. Another Israeli project (Passig and Levin, 2001) showed that young boys responded more successfully to multimedia tools when using a games interface.

A key paper on gender and ICT (Spender, 1995) includes data related to an early project that put laptop computers into a girls' school in Australia. The author suggested that girls and boys intrinsically respond differently to ICT. Another gender-based study in an Australian Catholic girls' school (Jones and Clerke, 1995) found that the key predictor for computer use among the girls studied was the extent to which they had prior experience with ICT. They also found that their confidence with technology was higher if they had been previously educated in single-sex settings.

In Taiwan, evidence was found for greater anxiety on the part of boys using ICT (Tsai, 2002), even though they were also more likely to be successful at learning co-operatively with it. Girls, on the other hand, responded well to a strategic learning approach.

Areas of ICT use such as programming have been historically seen as particularly male dominated. Some research interventions have sought to challenge this, with one project using female tutors to train the class in Logo (Edwards *et al.*, 1997). Other gender-related research has looked at this area within further or higher education settings or within adult education (Massoud, 1991). Even where these studies have shown potential achievement, it is difficult to be sure of the extent of the applicability to school-based learning and young people.

A Nordic study (Busch, 1995) investigated gender differences regarding attitudes to computers and perceived self-efficacy in the use of computers among

147 college pupils at a compulsory computer course in a college. A post-course questionnaire revealed gender differences in favour of males in perceived self-efficacy regarding completion of complex tasks in both word-processing and spreadsheet software. The researchers reported no gender differences in completing simpler tasks. They also found that male pupils had more experience in programming and games and were more likely to have been encouraged in their computer use by friends and others in their immediate circle.

A US study of undergraduates of a wide range of ages found that females were more likely to succeed if they were working in an all-female group rather than alone or with males (Corston and Colman, 1996). Overall, however, males performed slightly more effectively on the task set. Similarly, it has been shown that, at least at the time of the study, boys and men given computer-based tasks were more likely to succeed with these than were girls and women (Harrison *et al.*, 1992). Speed of operation was one of the main performance measures in the study. Boys were faster than girls and men were faster than women. The researchers concluded that 'the data presented here suggests that men and women in industry have much more similar levels of computer familiarity and awareness than is the case in schools, whereas in general boys at the end of compulsory schooling would appear to be much more computer-aware than girls.' (Ibid., p. 205.)

The different aspects of learning promoted by ICT use

In addition to the various aspects of learning discussed earlier, the development of interest in constructivist views of learning (where pupils' learning is based on them reconstructing and adding to their existing knowledge) has led to papers concerned with establishing the implications of this for ICT (Leask and Younie, 2001; Scrimshaw, 2001).

Pupils can be perceptive about their own learning with ICT (Irvine and Barlow, 1998), and it has been suggested that, given the opportunity, pupils are well able to engage in intelligent discussion of their own learning.

Collaboration

A definitive text on young learners collaborating around computers (Crook, 1998) suggested that this collaboration was productive and led to increased achievement. Of course, as had been made clear much earlier (McMahon, 1990), collaboration in classrooms is only possible if teachers are able to plan for and manage the process effectively.

One study provided paired keyboards linked to each computer (Peters, 1996), and this approach was reported to have provided considerable support to pupils who would otherwise have struggled. The researchers suggest that 'meaningful learning takes place when educators are creative in the way the computer hardware/software is used.' (Ibid., p. 229.)

More recently, researchers have paid attention to the kind of collaboration that takes place around computers and the scaffolding that they can facilitate. One study (Henderson et al., 2000) showed considerable evidence of the acquisition of cognitive skills as a result of such collaboration.

An analysis of the ways in which some primary-aged learners used computers collaboratively (Eraut, 1995) acknowledged the complexity of what had been observed but nevertheless provided a strong case for a Vygotskian[15] rather than a cognitive conflict[16] explanation of the learning process. This study is similar to past reviews in showing a learning advantage for computer-assisted instruction, but the authors contend that 'this gain in proficiency is an artefact of poor research design and comes about because of the superior quality of CAI materials, rather than some intrinsic aspects of computers per se, as vehicles of instruction.' (Ibid., p. 231.)

Online communities offer another arena for collaboration. One project found that the positive effects of co-operative online communities were greater where the learners were children than when they were adults (Susman, 1998). Similarly, eight-year-olds in Sweden were found to interact much more when engaged on ICT-based tasks (Svensson, 2000), although the difference may well have been more pronounced depending on what they had been used to previously.

[15] Vygotsky's theory emphasises social, cultural and contextual influences, and is based on the idea that learning is a process of internalising social and cultural values. Learning therefore takes place when there is social interaction and agreement between learners.

[16] Piaget argued that cognitive conflict is the principle mechanism for learning. This conflict occurs when there are disagreements between learners regarding their understanding of a problem, which is then resolved through teacher-led discussion.

Conclusions

The evidence from the literature shows the positive effects of specific uses of ICT on pupils' attainment in almost all the National Curriculum subjects. The most substantial evidence is in the core subjects of English, mathematics and science at all key stages. Other subjects in particular require further independent studies in order to substantiate the findings currently available.

Specific uses of ICT have a positive impact on pupils' learning where the use is closely related to learning objectives. The methods used to measure attainment need to be related to the learning experience which would be promoted by the specific use of ICT. Researchers need to take account of ICT leading to new forms of knowledge and knowledge representations and therefore new types of achievement.

There are a number of reasons why the evidence is more extensive and reliable in some areas than in others.

First, more research has been carried out into pupils' understandings and learning strategies in mathematics and science than in other subjects, and so there are more studies of the effects of specific ICT uses on attainment in these subjects.

Secondly, there are more subject-specific ICT resources available to teachers in English, mathematics, science and ICT than in other subjects, more use is made of these resources, and there is a greater body of knowledge about educational practices with ICT. As a result there is more evidence regarding the effects of ICT in these subjects than in others.

Thirdly, the amount of published evidence is greatest for those ICT resources which have been embedded in teachers' practices for a longer time. There is an emerging body of knowledge about the effects of the use of specific types of ICT such as email or the internet, but the evidence of the effects on pupils' attainment is not yet extensive. This is for two reasons: these resources are not yet widely used in the school curriculum, and they are generic by nature, hence it is more difficult for teachers to develop ways of integrating them into their subject teaching.

As the companion literature review to this study makes clear (Cox and Webb, 2004), the regular use of a wide range of ICT resources by teachers in lessons is far from common. Where teachers do use ICT it is usually confined to a limited number of resources and applications, for example using an interactive whiteboard for demonstrations to the whole class, or word processing for creative writing. Where teachers do report 'regular use' of ICT this may mean only a few minutes of use by individual pupils, or extensive use by some and much less by others. This variation in use affects the possible impact that using an ICT resource may have on pupils' learning.

As a result, the strongest and most substantiated results for the effects of ICT on pupils' attainment are in English, mathematics and science. Of course, it is important to remember that the evidence relates to specific uses of ICT, such as word processing in English, modelling in mathematics, or using simulations in science. Positive evidence in these areas does not mean that any or all applications of ICT will have similar effects.

Access to ICT in the home is helping some pupils continue with homework, share ideas via email, or send their work to the school's website. However, this home use is very varied and is not yet an integral part of most pupils' education.

There are three main groups of studies which have provided evidence of the effects of ICT on pupils' attainment: large-scale comparative studies, small-scale studies of specific ICT uses, and meta-studies of many small-scale studies.

Some of the large-scale studies, for example the ImpacT and ImpaCT2 studies, have shown a statistically significant positive effect of ICT on pupils' learning. However apart from the first project's mini-studies, it has not been possible to identify the actual types of ICT use which have contributed to these learning gains measured in the large quantitative studies. In the first ImpacT study, specific instruments, which were closely related to the types of learning being promoted by the uses of ICT, were used, and it was therefore possible for the researchers to measure the effects of the use of ICT on the pupils' attainment, for example in mathematical reasoning using Logo. This type of research has not attempted to separate out the effects of the teacher, but the results have shown that various uses of ICT have had a positive effect on pupils' attainment by relating the nature of the ICT-based learning tasks to the learning outcomes.

There is substantial evidence of the contribution of specific uses of ICT to pupils' learning from smaller focused studies, for example using simulations in science, modelling in science, ICT and mathematics, and

word processing in English. Many small studies have shown consistently positive results over the last 20 years, but this does not yet extend to all types of ICT use, nor does it exclude the input of the teacher.

It is important to recognise that because research studies often cannot factor out the influence of the teacher, it does not mean that there is no contribution from using ICT. Many small focused studies have identified learning processes and a more extensive range of skills and achievements which cannot be acquired in any other way. Therefore, in such studies, even though it is recognised that the teacher may have a very important influence, part or most of the learning gains can be attributable to the specific uses of ICT.

There are a range of factors which have been identified which will also influence the effects of using ICT on pupils' attainment. Many of these have been referred to in the subject sections above and centre on teacher pedagogy with ICT, including the types of ICT resources that teachers choose to use, their knowledge of the potential for ICT to enhance pupils' learning, and their ability to relate the ICT activity to learning goals and objectives. The research evidence on teacher pedagogy with ICT is discussed in detail in the companion publication to this report (Cox and Webb, 2004).

Another key factor is the use of ICT in different school and home settings. There are research studies which have shown that using ICT in informal settings (home, clubs and so on) can contribute to the learning experiences of pupils. However, few schools or teachers have yet been able to integrate pupils' ICT use in informal settings with their school use. More research needs to be done in this area to investigate how such activities at home or after school are contributing to pupils' attainment in specific subjects.

Further, the type of research study may also be important. Naturalistic studies measure the effects of the ICT uses which teachers have already chosen to use, while intervention studies introduce a specific ICT resource. In the former the evidence is more robust because the researcher is not intervening in the planning and use of ICT. Evidence from these studies has shown that the way ICT is organised within the school setting can have a large impact on the effects of ICT on pupils' attainment.

For example, in secondary schools most of these studies involve teachers using networks of computers, an electronic whiteboard, or a cluster of computers. These specific uses have shown that in the case of networks, teachers usually prepare an activity beforehand, then during the lesson act as a facilitator (see the companion literature review on ICT pedagogy (Cox and Webb, 2004)). This has the effect of teachers often not providing sufficient structure to the activity, which has been shown to be less effective regarding pupils' attainment. Small focused studies in naturalistic settings do, however, show a more planned approach to using networks, which has had a positive effect on pupils' attainment.

In primary schools, many studies continue to report the use of a few stand-alone computers shared between 30 pupils in a class. In these settings, the most frequently reported limitation was that teachers do not give pupils the opportunity to engage in substantial uses of ICT, such as drafting and revising their written texts, because their first priority is to give all pupils the same opportunity to use the computers. On this evidence, limited access to computers is having a detrimental effect on the contribution which ICT could make to, for example, pupils' progress in English and literacy.

A number of intervention studies have shown a positive effect on pupils' attainment where the uses of ICT have been closely related to curriculum objectives and specific concepts and skills. However, intervention studies have their limitations: it may not be possible to generalise results across other school and informal settings; also, studies may not be sufficiently long term to allow teachers to develop the necessary ICT skills and a sufficient understanding of the potential of the technology to demonstrate its potential.

More generally, there has also been a mismatch in some studies between the methods used to measure anticipated gains and the nature of the learning which is promoted by the specific use of ICT. In other words, researchers have often measured the 'wrong' things, looking for improvements in traditional processes and knowledge instead of new reasoning and new knowledge which might emerge from the ICT use. It is essential in any study that the actual types of uses of ICT are accurately recorded and measured as well as the effects on pupils' attainment. Studies which do not identify what specific uses of ICT are made by pupils may have difficultly in subsequently claiming any relationship between ICT use and attainment. The lesson from this review is that there is more robust evidence in studies

where the tests have been closely linked to the likely effects of ICT on pupils' learning.

In addition, detailed observations of pupils using ICT and of teachers' classroom practices can reveal pupils' learning strategies, the effects of interventions by teachers, and so on. This approach provides more in-depth data about the learning experiences of the pupils, which can then be related to measures of learning outcome. Similarly, pupils' products (word-processed work, presentations, and so on) and questionnaires completed by pupils and teachers can provide evidence of attainment and changes in understanding.

Finally, there is a growing body of research into pupils' use of the internet for sending and receiving emails, for using chat rooms, and for creating websites. Researchers have therefore analysed the text of emails and websites to assess pupils' development of new ways of communicating their ideas and presenting information. There is a large body of literature about knowledge representation, the recodification of knowledge, and research into artificial intelligence which needs to be used to inform research into assessing and interpreting pupils' ICT-based presentations.

Priorities for future research

In many studies, the use of more appropriate measures and a longer time-frame would have provided more robust evidence. It is also evident that it is not appropriate or possible to measure the effect of ICT on pupils' attainment without identifying what the actual use of ICT involves. Priorities for future research are outlined below.

First, more long-scale studies are needed, in order to:

- measure attainment which is sustained over a long period (at least two to three years)
- find out what effects specific uses of ICT have on the learning of concepts and skills in specific topics and subjects
- measure the effects of teachers' and pupils' ICT skills on the teaching and learning of specific subjects
- monitor and assess the whole learning process, which is made up of a wealth of learning experiences for every school pupil
- compare the effects of different uses of ICT on the learning of the same subject
- measure the effects of the use of ICT on the curriculum, and consequently on the learning of the pupils
- identify appropriate methods for measuring the effects of specific uses of ICT to take account of new ways of learning and new knowledge.

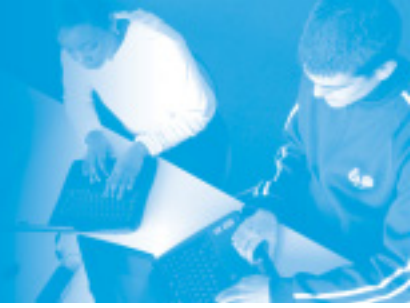
Secondly, research needs to be conducted to measure how informal learning experiences contribute to the whole learning process and thereby affect learners' achievements. Studies here could include monitoring the uses of ICT out of school and in school, measuring the effects of specific uses of ICT with specially designed instruments, and measuring the long-term impact of aspects of ICT on the retention of new skills and knowledge.

Thirdly, new methods of measuring attainment need to be developed. The research has shown that some methods of measuring the effects of ICT are more effective and reliable than others. A range of measures are needed to assess the effects of different uses of ICT on pupils' attainment, and also to assess the effects of other non-ICT-based learning experiences on attainment. The strengths and weaknesses of various measures also need to be identified.

Fourthly, more research needs to be conducted into the effects of specific uses of ICT on pupils' approaches to learning generally, on their meta-cognitive skills and on their long-term learning strategies. Many of the research studies reported here have focused on the learning experiences in a particular series of lessons. However, previous research has shown that using ICT in a lesson has positive effects beyond the classroom, as do many other learning experiences.

Lastly, a more extensive review of the literature (including more international sources, doctoral work, and wider fields such as psychology and artificial intelligence) would provide more substantial evidence of the effects of specific uses of ICT on pupils' learning and enable researchers to categorise groups of studies in relation to the types of ICT use more comprehensively.

For these reasons, and in order to capture the best and most effective uses of ICT in education, further research in this area should be a priority.



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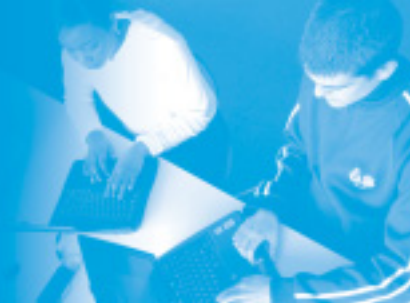

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