A review of the research literature relating to ICT and attainment

A report to the DfES by:

Editors: Margaret Cox and Chris Abbott; Authors: Margaret Cox, Chris Abbott, Mary Webb, Barry Blakeley, Tony Beauchamp and Valerie Rhodes;

Project Administrator: Montanut Turnbull; Project Consultant: Deryn Watson

All members of the project team are based in the Department of Education and Professional Studies at King's College London.

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Executive Summary

1 Introduction

This research project 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. This report is published in conjunction with a similar document which focuses on the available literature relating to the effects of ICT pedagogy on attainment (Cox and Webb, 2004). The two reports complement each other and serve to provide a good base for understanding the literature on ICT attainment and pedagogy.

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 findings of ImpaCT2 (Comber *et al*., 2002; Harrison *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.

The literature review procedure involved:

1. developing a framework of criteria based on existing evidence for deciding which literature should be used
2. identifying a common set of keywords relevant to ICT uses across the different types of published evidence
3. identifying and prioritising the range of journals and other published sources to be reviewed
4. conducting a review of research and statistical findings on issues relating to ICT and attainment
5. identifying the gaps in current knowledge about ICT in education.

The study involved collecting data from various sources including quantitative surveys and statistical publications, qualitative or case study data, and previously published meta-analyses. Most of the information has been derived from well-established and reputable paper-based and electronic information sources, such as academic journals and official reports. Other data were collected through internet searches and electronic databases. Apart from a few key documents, the review covered publications from 1990 to the present day.

The areas and types of studies for review included the following:

- 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, eg age, gender, class, ethnicity.
- Evidence relating to factors which might influence the learning outcomes, such as teachers' pedagogies, ICT environment, level of ICT resources etc.

2 Evidence of the effects of ICT on attainment

The evidence from the literature shows a positive effect of specific uses of ICT on pupils' attainment in almost all the National Curriculum subjects, the most substantial positive effects being in mathematics, science and English at all key stages. Evidence in other subjects has not yet been substantiated by enough independent studies.

There is a strong relationship between the ways in which ICT has been used and the resulting attainment outcomes. This suggests that the crucial component in the use of ICT within education is the teacher and their pedagogical approaches.

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There are many more uses being made of different ICT resources in mathematics, science, ICT and English than there are in other subjects. This means that there are a greater number of ICT resources available to these subject teachers, and there is a greater body of knowledge about educational practices for ICT in these subjects, and a greater body of evidence of the effects of ICT on these subjects.

The positive impact on attainment is greatest for those ICT resources which have been embedded in some teachers' practices for a long time. There is an emerging body of knowledge about the effects of specific types of ICT, such as email or the World Wide Web, but the evidence of the effects of these on pupils' attainment is not yet consistent and extensive.

There is substantial evidence from smaller focused studies of the contribution of specific uses of ICT to pupils' learning. These include 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, nor does it exclude the input of the teacher.

Mathematics attainment
There have been positive effects of ICT on pupils' learning of different concepts and skills in mathematics at both primary and secondary levels. These effects are more evident where research studies take account of the specific skills and tasks involved.

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

Science attainment
ICT has had a positive effect on many areas of science attainment. The types of ICT use, 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. This positive evidence includes improving understanding of science concepts, developing problem-solving skills, hypothesising scientific relationships and processes, and improving scientific reasoning and scientific explanations.

ICT attainment
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 ICT systems. 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 they could reach higher levels of abstraction and competency in the field of ICT.

Humanities attainment
Although there is less research reported here about the use of ICT in the humanities, there is evidence to show that using simulations can enhance students' reasoning and decision making in geography, history and economics. There is very little evidence of ICT being used or evaluated in primary schools for the teaching of geography or history, and clearly this is an area of the curriculum where more ICT use and research is needed.

Modern foreign languages
There is evidence of a positive effect 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 of a positive effect of ICT use has arisen when the specific skills developed by the software currently in use have been measured.

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Art, music, business studies and physical education attainment
Little research has been published about the effects of ICT in art, music, business studies and physical education. Some papers provide evidence of the enhancement of pupils' learning through specific ICT applications such as sound synthesisers in music, digital imagery in art, and ICT skills in business studies. More research in these subjects would be useful to show other teachers where ICT might enhance their teaching.

The effects of ICT on motivation and attitudes
Many studies report an improvement of pupils' motivation and attitudes to learning, shown through improved commitment to the learning task, greater interest in the subject, and pupils taking more responsibility for their learning and making sustained efforts in difficult tasks. Much of this evidence is gathered through observations and questionnaires. More research is needed that measures pupils' attitudes and motivation through established attitude tests.

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3 Factors affecting attainment

Many factors were identified which are often inextricably linked with the ICT-based learning experience. The most important of these are briefly reported here.

Teachers' pedagogies

These have a large impact on pupils' attainment. They influence the selection of the ICT resources, the preparation of the lessons, the way the ICT resource is used with pupils in lessons, the level of guidance and intervention and the level of ICT integration within the teachers' 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.

The uses of ICT in different school settings

The uses of ICT reported by the literature have often been influenced by the way the research was conducted. Naturalist studies 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 the teachers laptop computers. Intervention studies will affect the outcomes of any study because they will influence the settings in which the ICT is used, as well as the teachers' pedagogical practices. The majority of the large-scale comparative studies included in the review did not involve comparative studies of different school settings.

The uses of ICT included simulations in science, using word processing in English, and the Logo programming language in mathematics. In both types of research study, the majority of teachers used only a small range of ICT resources. There are very few published studies reporting on a single teacher using a whole range of ICT resources in their curriculum. This was even the case with the majority of ICT teachers. There are individual studies of other types of ICT resource, such as music synthesisers, tools for measurement and control, and English software, but considering there have been government programmes to support the use of ICT in education since 1973, our research has shown that the richness and breadth of the ICT resources actually used by teachers was disappointingly limited.

There is a growing body of research into pupils' use of the internet for sending and receiving emails, participating in chat rooms, and creating websites. Researchers have therefore reported analysing email texts 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 re-codification of knowledge and artificial intelligence research, which needs to be used to inform research into assessing and interpreting pupils' ICT presentations.

The use of ICT in informal settings

Using ICT at home or after school can contribute to the learning experiences of pupils, but not many pupils have yet integrated such uses with their school experiences. One of the reasons for this could be that teachers do not have direct control over what pupils do outside school hours. To increase such integration, teachers may therefore need to set homework tasks involving the use of ICT in a way which promotes and develops connections with home uses of technology. Teachers report that one of the benefits of such integration is that pupils can debate homework tasks among their peers, thereby challenging and extending their own understanding. Similarly they can share their ideas in a chat room, website or through emailing friends and/or the teacher. 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.

Ages of the pupils

The main factors affecting the differing impact of ICT on pupils of different ages were the different levels of access to ICT between primary and secondary pupils, the inappropriate use of an ICT resource for the ages of the pupils, and the low levels of tasks set for some pupils in relation to the scope for ICT use and the abilities of the pupils. Taking all the literature reviewed here into account, there was no reliable evidence that the use of ICT had a greater impact on any particular age group of pupils.

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Social and cultural backgrounds
There were some studies which measured the frequency of access to ICT among different social and ethnic groups, but there was no clear evidence of the effect of any inequality of access on pupils' attainment. More research needs to be done in this area.

4 Research methods to measure ICT use and attainment

In some studies there has been a mismatch between the methods used to measure anticipated gains and the nature of the learning which is promoted by the use of different ICT environments. Researchers have sometimes 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.

Research outcomes have been affected by many other factors relating to the research methods. These include:

- quality and depth of ICT use
- design of the attainment tests
- observations of pupils using ICT
- the analysis of pupils' products
- pupils' and teachers' questionnaires and records.

In conclusion, our literature review has confirmed that specific uses of ICT have had a positive impact on pupils' learning, where the use is closely related to learning objectives and where the choice of how to use ICT is relevant to the teaching and learning purposes. The methods used to measure attainment need to be related to the learning experience that would be promoted by the type of ICT use. Researchers need to take account of ICT leading to new forms of knowledge and knowledge representations, and therefore new types of achievement.

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Main Report

'*How can learning technologies improve learning? What the answer depends on is, of course, the context of learning. Any educational method depends for its effectiveness on the students, teachers, classroom style, institutional milieu, and so on, as much as on the material or method itself.*' (Laurillard, 1993, p.46.)

1 Background

This study was commissioned by the British Educational Communications and Technology Agency (Becta) on behalf of the Department for Education and Skills (DfES), as part of the ICT and Attainment project, to investigate the effects of ICT on attainment, based on evidence from the published research. This report is published in conjunction with a similar document which focuses on the available literature relating to the effects of ICT pedagogy on attainment (Cox and Webb, 2004). The two reports complement each other and serve to provide a good base for understanding the literature on ICT attainment and pedagogy.

Both studies were carried out by the same research team, and many of the procedures and methods used by the team were the same for both studies. A common feature of the two studies is the review of the published research literature. As is explained later in this report, the main aim was to investigate the most reliable and relevant published data to provide evidence of the effects of ICT on pupils' attainment. 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 controlling, modelling or data handling. Many previous 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 teaching and learning context and the abilities of the learners to use the technology. Therefore, in the literature review, we recorded details of these variables wherever they were reported, although not all researchers provide such details, particularly in large scale quantitative studies.

An important limitation of the research reported here is the four-month time-scale of the projects. It is usual in any larger research project to conduct a literature review alongside empirical research, and to include evidence from foreign as well as English language literature. It was not possible within the four months to review all the published evidence we know exists, much of which we have reviewed in previous studies. In order to utilise the evidence from this broader literature we have produced two literature bases. The first is a list of references to which the report specifically refers; these include a wide range of empirical findings and theoretical perspectives. The second is a bibliography which has informed and underpinned our approach and analysis. Much of the latter also describes specific examples relating to ICT and attainment and ICT pedagogy, which could be examined in more detail in a later study. Due to their large size, these two literature bases are published separately to this report.

Ideally a literature review compares findings from a number of different studies, which were perhaps conducted several years apart, or with different ages of pupils or in different educational settings. Although we did not have sufficient time to be able to do this with all the publications, the evidence we have compared provides very useful findings, and has implications for further research and about the effectiveness of different research methods. One of the main findings from the two studies is the need for a larger and longer-term literature review which would be able to draw out relationships between specific ICT use and the effects on attainment within a range of contexts.

2 Introduction

Ongoing evidence from 30 years of ICT development and evaluation programmes has revealed a growing number of issues relating to the impact of ICT on teaching and learning and on the uptake of ICT in education. This, alongside the many other research projects conducted by ourselves and colleagues at Kings College London, has provided a large range of research instruments and methods, as well as empirical evidence of their effectiveness in measuring pupils' attainment using ICT. This has informed the literature review methods that have been used in this study, and the range of literature reviewed. The study was of four months' duration and the details of the research methods and evidence from the literature review are provided in the following sections.

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3 Aims of the study

In order to investigate the effects of ICT on attainment, based on evidence from the published literature, the research team had the following aims:

1. To identify and use reliable, well documented sources of evidence from the published literature.
2. To consider evidence from this wider research literature relating to ICT and attainment to build on the ImpaCT2 findings.[1]
3. To identify the range of environmental, contextual and institutional factors that may have an impact on the association between ICT and improvements in attainment.
4. To provide an analysis of key issues revealed from the literature review for further research.

4 Methodology

Various categories of data were extracted from the literature included in the review in order to achieve all of the aims described above. This process also provides a framework for future literature reviews. One of the objectives of the review process was to develop some common understandings about ICT and attainment that will underpin future ICT education research projects. The literature review process involved:

- developing a framework of criteria, based on existing evidence, for deciding which literature should be used
- identifying a common set of keywords to be used across the different types of published evidence
- identifying and prioritising the range of journals and other published sources to be reviewed
- conducting a review of research and statistical findings on issues relating to ICT and attainment
- identifying the gaps in current knowledge about ICT in education.

The study involved collecting data from various sources, including quantitative surveys and statistical publications, qualitative or case study data and previously published meta-analyses. The emphasis was on identifying work that was both original and nationally important, as well as having addressed relevant issues. Additional attention was also given to the correctness of available literature, the level of accuracy of the reported results, the variables considered and the applicability of results. Most of the information has been derived from well established and reputable paper-based and electronic information sources (see Section 5), but internet searches were also used.

It should be noted that this literature review did not include a statistical meta-analysis because of the limited time-scales. The methodology is explained in the following sections.

4.1 Literature search procedures

The first stage of the study involved establishing procedures for reviewing the literature review to ensure a systematic and relevant approach. This was especially important given the short time-scales of the project. The following strategies were agreed:

- Combining existing literature reviews and creating a framework for the evaluation.
- Deciding the criteria for the selection of the literature sources (eg the journals chosen and other web-based sources and official reports).
- Identifying and prioritising the range of journals to be reviewed and the relevant reviewer for each journal, decided according to expertise.
- Developing a set of keywords, which would form the basis for the framework, enable the project to achieve consistency across reviewers and allow keyword searches for analysis.
- Identifying the gaps in current knowledge about ICT in education.

4.2 Combining existing literature reviews and creating a framework for the evaluation

As a starting point, members of the review team contributed relevant articles from their existing literature reviews in ICT and education, which were used to develop an agreed framework. The framework was continually modified as additional evidence was analysed. To contribute to this framework and the review procedure, the team identified important categories for review (see Section 4.4).

[1] ImpaCT2 was a major study carried out between 1999 and 2002 involving 60 schools in England, and was one of the most comprehensive investigations into the impact of ICT on educational attainment so far conducted in the UK. It was commissioned by Becta on behalf of the DfES. (Comber *et al*., 2002; Harrison *et al*., 2002; Somekh *et al*., 2002)

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Each of the publications included in the review was analysed and assigned keywords relating to the particular factors associated with ICT and attainment which it focused on. The full list of keywords used can be found in Appendix 1.

The publications included in the review were also categorised and given keywords according to the curriculum subjects they focused on (for example geography, science, or literacy). Whenever possible, synthesis studies were used to winnow out the particularly relevant studies from the aggregate set of literature.

A number of ICT solutions were considered by the team for the recording and storing of the data extracted from the included publications. The final decision was to use Endnote because this would ensure consistency across the reviews for the different sources, and as the data could then be easily used with any published document produced from the project.

4.3 Deciding the criteria for the selection of the literature sources

The criteria which were agreed for selecting the literature sources were the following:

- Sources would be searched from documents, web materials, etc, published from 1990 to the present day. This was to enable us to include some of the important large-scale studies conducted during the early 1990s.
- Only English language literature would be used due to the limited duration of the project.
- Journals and articles would be prioritised according to their coverage of research in ICT and education, their relevance to Key Stages 1–4 (learners aged 4–16 years), and relevant theoretical and empirical areas.
- Web-based sources would be searched according to the keywords we had established, and the refereeing system for web publication which had been used (i.e. academic papers published on the web which had had peer reviews, but not personal publications by individuals with no obvious review method).
- Research reports on work conducted in the UK would be reviewed before reports of work in other countries.

4.4 Identifying and prioritising the range of journals to be reviewed

Using the set of keywords that emerged from our previous literature reviews and our existing literature databases, we identified a list of academic journals to be reviewed according to the priorities explained below. The full list of journals is given in Appendix 2, with Appendix 3 showing those prioritised to be reviewed first. In using these keywords, we therefore reviewed literature which was directly relevant to Key Stages 1–4 in the UK, i.e. primary and secondary education and special needs. We also reviewed other academic publications where possible, where the theory or empirical evidence was relevant but was focused, for example, on a tertiary study, or informal learning at home. The ways in which the evidence was collated and categorised are detailed in Appendix 4.

5 Literature review data sources

The types of sources which we have used, as explained briefly above in Section 4.4, include the following:

Paper-based resources, including:

- academic journals listed in Appendix 2
- research reports
- books
- monographs
- PhD theses.

Electronic resources, including:

- research reports
- *Educational Technology Abstracts*
- *Sociology of Education Abstracts*
- Sociological Abstracts bibliographic database
- The Educational Resources Information Center (ERIC) and ZETOC, which provide online access to the British Library's Electronic Table of Contents database of over 15 million article titles derived from

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the 20,000 most important research journals in the world, dating back to 1993. It is updated daily with approximately 10,000 new additions
- academic journal papers published online
- conference proceedings.

6 Results of the literature review

The results of the literature review are presented here.

6.1 The ways in which ICT has been used and the resulting attainment outcomes for Key Stages 1–4

The evidence from our literature review shows a strong relationship between the ways in which ICT has been used and the resulting attainment of pupils. This suggests that the crucial component in the use of ICT within education is the teacher and his or her pedagogical approaches. Excellent software, reliable hardware and resilient networks, important though they may be, will have no effect on attainment if teachers are not enabled and educated to use these resources appropriately. It is no accident that the word 'assist' forms part of even such outmoded terms as computer-assisted instruction (CAI) and computer-assisted learning (CAL). Educationists stopped thinking of technology in the form of teaching machines in the 1960s (see for example *Computers in Education*, volumes 5–12).

The range of research publications for the different curriculum areas and levels of education vary widely from one subject to another and between primary and secondary education. It was beyond the scope of this review to search all the papers published on the web from other countries, which might, in a later review, provide some additional evidence of value to future projects. For the purpose of these two short projects we have structured the following sections to include both primary and secondary education in the same section for each subject. Where there is relatively sparse evidence in some subjects, for example in modern foreign languages, we have not provided a separate 'Conclusions' section because it was not warranted. As will be seen, the evidence from the literature review has different implications for different age groups and sectors, which are explained in the conclusions.

6.1.1 The effects of ICT on attainment

Key documents published in the UK on ICT (DfE, 1995; DfEE, 1997) have consistently viewed learning gains as potential outcomes for the use of this group of technologies. However, other countries have taken different views. Sweden (Ministry for Education and Science, 1998) sees the main purpose of ICT as enabling communication with other countries. Finland is seeking to use ICT to help its citizens take part in the 'information society' (Ministry of Education, 1999); and one Australian state suggested that the key area to be addressed was the ability of ICT to give a voice to students (Dept of Employment Education Training and Youth Affairs, 1997). US reports have provided useful summaries of the debates in the years when much ICT use was restricted to only a few countries (US Department of Education, 1993).

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 (1993): 'There is a persistent discrepancy between the questions asked of evaluation studies in new technology, and the conclusions they come to.' (p.46.) In her research into ICT and attainment, she has repeatedly shown that the context determines any effects which ICT may have on attainment, and that it is extremely difficult to separate the impact that the context has on attainment from the specific uses of new technologies. This research is supported by a timely paper by Joy and Garcia (2000), who argue that it is not the effect of ICT alone on learning gains which should be studied, but the combination of ICT with particular pedagogical practices, and this point is echoed elsewhere (Kennewell, 2001). However, this literature review is providing evidence of a positive impact of ICT on pupils' attainment, where the methods of research have been specifically designed to relate to the particular types of learning experience promoted by the use of ICT, as is explained in later sections.

It is also important to note here 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

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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 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. Eighty-three per cent 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 methodological basis for some ICT research has been consistently criticised (Selwyn, 1997; Selwyn, 2001; Reynolds *et al*., 2003). Evidence from the literature has shown that methodologies have sometimes limited the effectiveness of research. For example, a recent Finnish study of 515 school students (Hakkarainen *et al*., 2000) suggested that ICT had made learning in secondary schools more effective and meaningful, but this was based on data collected from student self-assessment questionnaires. Such methods do not assess actual learning outcomes, but only the students' perceptions of the experience and its possible benefits to their learning.

A Scottish study (Condie *et al*, 2002) sought to discover the extent to which ICT resources contributed to learning for almost 3,000 students in 80 secondary schools. Questionnaires and test booklets were used, but the only gains recorded were in ICT knowledge and skills.

Other research has focused on learning gains 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 students. This begs a number of questions, however, particularly about the definition of 'writing' used here. The setting was a US composition-writing class, a very different context from, for example, a UK literacy hour lesson. Findings are all too often interesting, but it is not possible to generalise them in this way.

Researchers in the United States 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 *et al*., 1999), and results of these US studies are discussed later in the report.

A project in Israel considered the role of animation in the teaching of programming (Ben-Bassat Levy *et al*., 2003). It was found, after using a parallel animation and non-animation methodology, that the actual difference created by the use of multimedia was measurable but small. The team reported that the most able students did not need the animation tool, and the lower ability students could not use it. However, they did feel that it was useful for some students in the middle ranges of ability, although they provide no empirical evidence for this supposition. Many previous research papers have reported on the use of modelling to support the teaching of programming (Lavonen *et al*., 2003) and causal reasoning using modelling (Mellar *et al*., 1994), and have reported significant success, as is explained later (see Section 6.2.2.4).

Longitudinal studies are beginning to produce findings that add considerably to the research field. The first report (Goodison, 2002) from a three-year study of three primary schools, looking mainly at the criteria for successful 'integration' of ICT, focused on the way that ICT is organised in the school. However, the paper contains nothing on gains in attainment.

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

Apart from the ImpaCT2 study (Comber *et al*., 2002), comparatively little attention has been paid to the use of ICT in the home, although papers are beginning to appear (Mumtaz, 2001; Mumtaz, 2002). Personal digital assistants (PDAs) have been used in some schools as a way of providing access to ICT

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resources at home and school, and as a means of linking the two sites together. Little research has yet been done in this area, but one paper (Hennessy, 2000) found little evidence of any improved learning gain over the use of the same tools on a desktop, although the students were motivated by access to this hardware. Other papers (Robertson *et al*., 1997; Newhouse and Rennie, 2001) described issues such as the difficulties experienced by students using laptops which could be taken home (although these were low-specification computers compared with the desktop models available at the school), or the failure of students to make use of ICT facilities at school (Selwyn, 1998) 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 teacher development in the application of the technology, carefully selecting appropriate packages for use in the classroom, and encouraging pupils to collaborate fully with others online.

The ImpaCT2 project included case studies of 15 of the 60 schools involved in the project, 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 topics on the internet for homework, sharing ideas for answering questions using chat rooms, and text messaging on mobile phones, plus some use of email to share ideas about school work. 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 school computers for pupils. 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.

6.1.3 Differential access and use in relation to social characteristics [BOLD]

Provision in rural areas has been a major factor for some parts of the UK such as Scotland, and also for some other countries. In Norway, a particularly sparsely-populated country by European standards, proposals have been put forward for municipal ICT schools (Hartviksen *et al*., 2002) which will support other more rural districts, and similar discussions have taken place in Finland (Husu, 2000). In many ways, this is a variation of the specialist school model that has gained credence in the UK in recent years. Video conferencing has been shown to be successful in these rural areas (Thorpe, 1998). Attention has also been paid in Norway to the potential of email for supporting student teachers on placement (Hoel and Gudmundsdottir, 1999), a methodology echoed in other papers (White and Le Cornu, 2002). Other publications in this area are about access for special groups, such as travellers' children, but it is beyond the scope of the project to review all of those.

6.1.4 The changing nature of educational ICT resource provision

During the late 1980s the US educational software marketplace was dominated by integrated learning systems (ILS), 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 academic writing on this topic had moved on from attempting to measure learning outcomes (Bentley, 1991; Becker, 1992; Fischer, 1996) to considering the ways in which these systems might be improved and made more effective (Becker, 1992; Maddux and Willis, 1992; White, 1992; Hativa and Becker, 1994).

During the mid-1990s the UK Government invested in a large-scale evaluation of ILS resources. The changing groups of researchers involved in the project issued a series of reports and also published academic papers (Underwood, 1994; Wood *et al*., 1999) commenting on their involvement and the outcomes of the evaluation. The first report of the UK evaluation (Detheridge, 1994) was written in house by the National Council for Educational Technology (NCET). The report was broadly positive, and was presented as 'a valuable interim assessment pending the results of a broader-based project' (p.6). It was reported that children had made learning gains in mathematics, although not in reading. Interestingly, learning gains were inversely related to children's own perception of their progress. This facet of ILS may explain some of the perplexing differences between what research shows and what teachers and governors feel about it.

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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 to all intents and purposes a new research project. The emphasis had changed to being the repeatability and transferability of such learning gains as had been identified. A larger group of schools was involved in this second phase of the evaluation. As this research was publicly funded, there was a need to study more than one ILS product in order to avoid suggesting any bias towards one commercial company. This caused complications for the methodology, as it meant that for many readers, especially distributors and potential purchasers, these reports were sometimes misread as evaluations of the specific ILS products involved rather than of the ILS concept itself.

The third report (Wood *et al*., 1999) added other reservations, particularly in the statement which formed the foreword. After pointing out that the evaluation had been the largest independent study of ILS 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 ILS, but that it can be difficult to establish exactly what might be the nature of that 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 ILS 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) has tended to focus on particular aspects of classroom ethos and pedagogical change rather than trying to measure learning gain. Recent research from the US (Brush *et al*., 1999; de Castell *et al*., 2002) has shown that the more explorative and problem-solving aspects of some ILS products are more effective than the traditional foundation activities, and that a rethinking of the role of ILS may also lead to a helpful re-examination of ICT in education as a whole. One message appearing more frequently in the ILS research (Powell *et al*., 2003) is an indication that not only does success with ILS relate to the pedagogical approach adopted by the teacher, but that it may also depend, perhaps paradoxically, on students being self-directed enough to make appropriate use of the resource.

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

Specific studies have been conducted over more than 30 years into the effects of ICT on attainment, and we have presented evidence from the more recent ones here. Again and again, the pattern is of minimal evidence of measurable attainment as a result of ICT use, and yet indications from researchers was that fundamental but hard-to-measure change was suspected to have taken place.

An Israeli study in the early 1990s (Klein and Nir Gal, 1992), which looked at very young children, found little evidence of the kind the study was looking for, but the researchers reported interesting changes in the extent to which the group using computers more frequently paused to think and to talk about what they were doing. Another Israeli study (Offir and Katz, 1990) reported that it was those teachers willing to take risks who were most likely to be effective users of ICT, although this was within a CAI (computer-assisted instruction) framework rather than within a model of ICT-supported learning. There are echoes here of Papert's characterisation of the lone enthusiastic teacher in the first wave of a new technology, followed by unquestioning acceptance by the many and only then a critical awareness of the potential (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 that from the USA – seems to be grounded in assumptions about transmission of information rather than situated learning[2] or collaborative

[2] Situated learning is that which takes place in a relevant context. Advocates of situated learning argue that this is the only way in which students 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.

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enhancement through scaffolding.[3] Other writing may be based on particular views of the learning process such as that of Laurillard (1998), who sees it as an iterative cycle of discussion, interaction, adaptation and reflection. In the paper, the author goes on to argue a convincing case for the educational value of narrative in multimedia.

A significant problem for research into ICT and attainment 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 ICT environments. 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.

6.2.1 Meta-studies which have measured the large-scale impact of ICT on attainment

The early days of IT and ICT in schools were characterised by writing which wedded an optimistic tone to an absence of suitable data (Hawkridge, 1990), although many important issues were raised and much was achieved by these publications.

NCET and later Becta 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). Other literature reviews are currently in progress (Selwyn, 2002; Wegerif, 2002). These publications often provide information about the contribution of very specific uses of ICT to learning, rather than large-scale evidence of the effects of integrated ICT use on attainment.

More recently, one paper (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 showed a range of pedagogical practices, but often a minimal input from the teachers compared with other more conventional activities. Most of the learning activities involved searching for information, with few other uses of the internet such as guided online debates or using interactive software.

6.2.2 Research evidence relating to specific curriculum subjects

Much ICT research based 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 across the curriculum. The results of this literature review and analysis of this area are presented here.

6.2.2.1 ICT in mathematics attainment

In many ways, little seems to have changed since Becker's 1989 IEA[4] 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 per cent of pupils never or hardly ever used ICT in mathematics lessons, and at Key Stage 4 the figure was over 80 per cent. In a series of articles arising from an Economic and Social Research Council (ESRC) 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.

[3] Scaffolding is where pupils build up knowledge and understanding by linking new concepts to those previously understood through a mental framework of linking concepts.

[4] International Association for the Evaluation of Educational Achievement

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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,[5] 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 (Cox, 1993). These included:

- different subject- and topic-based tests for the longitudinal study, 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 which collected data on the kinds of use of ICT being made by the pupils, and when and where this occurred in school and at home.

In the case of mathematics, pupils aged 8–10 and 14–16 in classes which were using Logo[6] and subject-based mathematics software, achieved statistically higher scores in the post-test 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 skills using databases.

In the recent ImpaCT2 study, evidence was also found that ICT had a positive impact on pupils' learning of mathematical skills (Harrison *et al*., 2002), and the results varied according to the level and type of use of ICT in the mathematics curriculum. One of the limitations of this 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 weekly pupils' and teachers' reports on types and frequency of uses of ICT in the curriculum from the cohort of 2,300 participants over a two-year period, augmented by a series of longitudinal case studies. This provided enough information to be able to relate the ICT uses more specifically to the mathematics attainment (Watson, 1993).

In a study in the USA, 42 students taught by the same teacher were the subjects of a study (Arthurs *et al*., 1999) which sought to discover the problem-solving techniques utilised by students within a mathematics lesson. Among the resources provided to some of the students was a meta-cognitive software package designed to support inductive reasoning. It was found that those students 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 students' practices.

In the UK, another research team found evidence that it was those teachers of mathematics who thought of the subject as 'a connected network of multifaceted ideas' (Askew *et al*., 1997, p.19) who were judged to be among the most effective practitioners.

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[5] The first ImpacT project was a three-year study commissioned by the then Department for Education to evaluate the impact of ICT on children's achievements, and was published in 1993 (Watson, 1993). This work was then followed up by the ImpaCT2 project, a study carried out between 1999 and 2002 which continued the investigation into the impact of ICT on educational attainment (Harrison *et al*., 2002; Somekh *et al*., 2002; Comber *et al*., 2002)

[6] Logo is a computer programming language, originally designed to aid the teaching of mathematics. It is now used in a variety of topics to assist teaching and learning in a range of subjects.

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Christmann *et al*. (1997) provided a meta-analysis from the USA comparing the academic achievement of students from grades 6 to 12 who received either traditional instruction or traditional instruction supplemented with computer-assisted instruction across eight areas of the curriculum. From the 42 conclusions, an overall effect size of 0.209 was calculated, indicating that, on average, students receiving traditional instruction supplemented with computer-assisted instruction attained higher academic achievement than did 58.2 per cent of those only receiving traditional instruction. The mean effect size[7] for mathematics was 0.179.

In England, Becta (2001) reported data from the DfEE survey (2000) of 714 secondary schools, used to identify schools using ICT to support English, mathematics and science. Better results at Key Stage 3 (except in English) were found in schools using ICT compared to non users. Higher GCSE results were found in schools with more use of ICT across the curriculum. Inspectors' assessments of schools with good resources, good ICT teaching and good use of the resources were used to show better attainment at Key Stages 3 and 4 compared to poor schools. A consistent difference was found in attainment between those schools with good ICT resources and those with poor ICT resources. There was not the same consistency between other levels of resources. However, no causal relationships were established.

The ImpaCT2 project (Harrison *et al*., 2002) reports that at Key Stage 3, high ICT users outperformed, on average, low ICT users in mathematics, with differences at Key Stage 4 being slight. Once again, causal relationships were not established. Hennessy and Dunham (2002) point out that 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, and fair comparisons using test scores alone are almost impossible. However, ICT itself can play an important role in shaping the mathematical activity.

In view of the central position of mathematics within many integrated learning systems, some integrated learning systems research projects have also considered the role of these systems in increasing mathematics attainment or understanding. The UK evaluation previously discussed 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 classes (Becker, 1990) by the same researcher who went on to write widely on integrated learning systems (Becker, 1992) and then to head the Teaching, Learning and Computing survey. 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 students in 75 classes. Although a recent paper from the programme (Brown *et al*., 2001) does not address the use of ICT overtly, there are insights into 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 ILS. Researchers in Hong Kong considered the extent to which skills gained in programming with Logo could be transferred to new contexts (Au and Leung, 1991). 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.

Other research has also been published (Waxman and Huang, 1996; Shyu, 1999; Panagiotakopoulos and Ioannidis, 2002; Tanner and Jones, 2002; Yelland, 2002; McDuffie and Slavit, 2003) on the use of ICT in mathematics education. Recent research includes a Finnish project which looked at the learning styles found to be most effective in a lesson using Logo (Suomalo and Alajaaski, 2002). They found that the most effective learning styles were those that were related to discovery methods rather than teacher direction.

[7] Effect size is the difference between two mean score values. A positive effect size of 0.2 shows that there is a small but statistically significant difference between the experimental and control groups' scores. A medium effect size would be 0.5, and a large effect size would be around 0.8. Effect size is independent of the sample size.

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An Australian study (Ainge, 1996) examined the use of virtual reality for teaching geometry within Aboriginal communities. Although the sample size was small, evidence was found of better shape recognition in the group using virtual reality tools than was found in the small control group using card nets. Ease of use of virtual reality and student engagement were noted informally, as was, however, the failure to note any improvement in visualizing and naming shapes

6.2.2.1.1 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

As is well known, 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) summarises research on Logo as follows: 'Used appropriately, computer programming has been shown to help students:

- 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 students' social interaction patterns.' (pp 28-29)

Hoyles *et al*. (1991) analysed the processes whereby pairs of secondary school pupils (12–13 years old) 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 generalization...Formalization 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 student behaviour in a Logo-based micro world,[8] constructed around the notions of ratio and proportion, showing that teacher intervention was crucial in enabling the pupils to create successful 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, eg, Logo micro worlds, would become the school mathematics curriculum has clearly failed to gain the support of the educational system.' (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 syllabus. His results showed that students in the experimental group had a deeper understanding of fundamental concepts in geometry. He concluded that the experimental group performed better because of the Logo programming exercises and Logo tutorials. In another study Logo-

[8] A Logo micro world is a piece of software which provides advanced features, such as user-friendly environments and multimedia functions, for use with Logo programming.

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based instruction was applied in the teaching of basic geometric concepts (points, rays, lines and line segments) (Yusuf, 1995). The experimental group produced significantly better results in terms of the in students' achievements and the students' attitudes.

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.' (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 students 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 engaging even relatively weak students to deal in depth with difficult topics. They 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 ESRC's project InterActive Education: Learning in the Information Age. It focused on using a graphical software package to assist learning and understanding of quadratic functions, and included a discussion of how the structuring of the activities influences the nature of the learning environment and how it might influence students' exploration of mathematical concepts.

Closely linked to the skills of solving quadratic functions are the abilities of pupils to be able to interpret graphs, an area which has been enhanced by many ICT-based packages.

Graphs
A major component of ICT interfaces has been that of 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) investigated data logging, using portable computers, as part of an investigative approach to science. 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 14, which is not necessarily repeatable at 16.

Hennessy (2000) evaluated the use of palmtops with 23 year 9 students in study 1, and 25 year 8 students in study 2. The main gains were in the motivation of the students, and 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 the computer medium 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.

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Computer algebra systems (CASs)
CAS has also been a recent focus of attention. Herget *et al*. (2000) claim that mathematics education will not become simpler. 'A consequence of the new tools is that mathematics becomes more useable and probably more demanding, but definitely not simpler.' (p.11)

Exposition has an impact on teaching methods, training methods, homework, curricula, and what teachers need to know. Gardiner (2001) was 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? Monaghan (2001), in a series of articles, claims that the conscious use of the algebraic capabilities of, for example, a CAS calculator, may help students to focus on suitable forms for 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 students talk about the tasks and techniques and so develop a specific language which they can then use to consider the consistency and the limits of the techniques. Techniques without schemes are ineffective since they are not likely to evolve and cannot produce knowledge.

In one of the few studies to report specific gains, Shaw *et al*. (1997) used a CAS 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 CAS teaching software, 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 the introductory statistics course were: traditional, 1.81; college, 2.50; technology, 2.52. These results showed that the students using the CAS 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 (ethnicity and gender), and found no difference.

Calculators
Finally Jones and Tanner (1997) reported on a research study to explore the effects of the use of calculators on the basic arithmetical skills of Welsh secondary school pupils. Three models of use emerged: 'available' 'discouraged' and 'restricted'. A test of basic skills given to all year 8 pupils in 11 schools showed no significant gender differences, neither were significant differences found between pupils from the three models above, but pupils who reported that they used calculators did better than pupils who did not. Compared with standards from the 1970s, facility with fractions had decreased, but scores in number and decimals were on a par. The authors concluded that the results 'suggest that calculators were not being best used to improve pupils' learning.' (p.34)

6.2.2.1.2 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.

6.2.2.2 ICT in English
Although teachers of English in the UK may not have been early adopters of ICT, they have been exposed to the issues regarding the use of ICT in English 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.

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One study of the use of computer-aided 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. Literature has also formed the focus for other studies (Clarke, 1995) although in some cases (Darby *et al*., 1997) the focus has been more on evaluation and case study than on the discourse of research.

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 online in a reflective community of practice (Leach, 1997). Of course, as has been shown since the early 1990s (Kay and Mellar, 1994), very few new teachers feel totally prepared for the use of 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 in their school placement (Trushell *et al*., 1998).

Much other research into the use of IT and 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 been taken an optimistic, non-critical view of technology, although this has changed considerably in recent years.

Where there has been an attempt to measure attainment outcomes of 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). Teacher-based research into pupils writing hypertext documents[9] (Russell, 1998) has raised key questions about the need for a re-examination of the role and practices of the teacher, and also reflects on the resistance likely to be encountered as this process develops and gathers momentum.

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 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 (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. 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 English in some contexts. In the case of the first ImpacT project (Johnson and Trushell, 1993), there was a statistically significant effect of using word processing on pupils' (aged 8–10) attainment in English, but only a partial and not statistically significant effect for pupils aged 12–14. 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 orthography. The main findings from this study in primary pupils' English were 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 ImpacT high IT primary classes relative to the ratings given for content and cohesion. When pupils composed directly with word-processing facilities, particularly on the mini-study assessment, they were more prone to summarise and remove redundant information.' (Johnson and Trushell, 1993, p. 114.) However, the actual level and frequency of ICT use reported by the pupils was at most three to five times a term for each pupil, sometimes for only a few minutes. At the secondary level the results were less conclusive partly because

[9] Hypertext documents are usually presented by a computer, and contain a web of links to separate but related texts. They express the non-linear structure of ideas.

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of poor returns on the English essays, and again because of the limited use of ICT in English lessons. With such an infrequent use of ICT in English, it is perhaps surprising that there were any measurable positive effects on attainment.

Ten years later, the ImpaCT2 project also showed 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, did 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); this 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 computer speech input and output led to a flurry of interest on the part of publishers and then researchers in the potential of talking books, although these have not gone on to become quite the force that was expected, perhaps because the World Wide Web has become a more likely narrative repository. Nevertheless, work at the Open University (Lewin, 1998) showed that talking books can help with single-word recognition or sight vocabulary, but that they were largely ineffective at building phonological awareness.

Another UK study in this area (Underwood and Underwood, 1998) chose to focus on the peripheral animations and other interactive facilities which surround and enhance the ICT-based text in a talking book. It was found that, although children enjoyed these features, any skills learned did not carry over into 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 total immersion might result in a user experiencing 'cognitive overload' when trying to understand conceptual notions.

In another recent study (Lynch *et al*., 2000) researchers measured the effects of a support program designed to help with the teaching of reading, using computer-generated speech. The results showed considerable gains, at least as measured with traditional and limited test instruments producing reading ages, speed, etc. This led the researchers to conclude that such software has potential for all children in secondary school experiencing difficulty with reading, although this is perhaps a surprising claim since their sample involved only eight pupils.

Word processing has, not surprisingly, been a central focus for researchers working within this subject (Murray, 1992; Wolfe *et al*., 1996). As at least one recent paper has shown (Mumtaz and Hammond, 2002), word processing is still not fully embedded, or used effectively, in many UK primary classrooms. Inappropriate use of word processing, especially the metaphor which has been internalised by many teachers and parents of the word processor as desktop publishing tool or printer, has marginalised its true potential as a means of drafting and revising, despite this model having been proposed in curriculum documents for many years.

A study by Allen and Tompson (1995) considered the use of word processing in a networked learning environment and how this might offer access to real audiences for writing. The project 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 males in the networked group compared to those in the control.

A related project (Haymore Sandholtz *et al*., 1992) investigated the effects of ICT use on classroom management issues. The study highlighted three issues relevant to practice and research: the need to continue to develop classroom management skills; educational change takes time; and 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

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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.' (Haymore Sandholtz *et al*., 1992, 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, although the results were not supported by any standardised test scores. The paper does, however, contain descriptions of a selection of interesting examples of the ways in which computer-mediated communication was used during the project.

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. Students were randomly assigned to a group writing by hand or one using computers. 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, however, about the extent to which these outcomes are related to the technology intervention rather than to past and present teaching styles and expectations.

There is a growing body of research (McBride and Seago, 1999; Cummins, 2000) related to the use of ICT within Teaching English as a Foreign Language (TEFL), English for Speakers of other Langauges (ESOL) or English as an Additional Language (EAL) classrooms (Silver and Repa, 1993; van Haalen and Bright, 1993; Ward, 1996), or the equivalent in non-English-speaking countries. A study of preschool 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 students learning English as a foreign language. She measured the impact on attainment through a quantitative study of over 100 pupils, using pre- and post-tests 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 students, 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 more curricular-prominent skills of reading and writing. 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).

6.2.2.2.1 The effects of ICT on English attainment – conclusions

The evidence discussed above shows 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 results which show both positive and negative effects of word processing, such as the study by Barker and Pearce (1995), who found that undergraduates made fewer punctuation errors but more passive constructions. In contrast, 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 pupils, with little opportunity for drafting and redrafting – through which the most positive effects have been identified. The most positive evidence arises from primary pupils' use when they are at the early stages of language development and they have a chance to compose and reflect on their compositions.

6.2.2.3 ICT in science

During the early years of ICT use, science classes were the site of various innovations. Modelling was used to build an understanding (Brna, 1990, 1991) of students' misconceptions, and has been shown to enhance students' 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 what is happening in the classroom.

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Some recent studies in science have suggested that high levels of ICT use may be linked to improved attainment. In an analysis of inspection data from the Office for Standards in Education (Ofsted) for 1998–99 based on results from 2,500 primary schools (Becta, 2001), a significant statistical correlation (0.06) was found between the grade given for ICT resourcing by inspectors and the science attainment grade 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 for 1998, 1999 and 2000 for Key Stages 3 and 4, based on results from 409 secondary schools (Becta, 2001), consistent positive differences were 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 resourcing.

In a further study the relationship between good use of ICT and standards of achievement is analysed from the Ofsted inspection reports of 2,582 primary schools (Becta, 2003). Here Ofsted inspection judgements are 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, these studies did not analyse causal relationships, and other factors such as good leadership and general quality of teaching may be more important than ICT use, but 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 predetermined criteria including a research design that was experimental, quasi-experimental or correlational. The meta-analysis, which used sample sizes that combined a minimum of 20 students in experimental and control groups, indicated that students receiving traditional instruction supplemented with computer-assisted instruction attained higher levels of academic achievement than did those only receiving traditional instruction, and that the effects on science achievement were greater than the effects in other subjects. The comparative effectiveness of computer-assisted instruction may be seen in the following list, in descending order, of mean effect sizes: science 0.639, reading 0.262, music 0.230, special education 0.214, social studies 0.205, mathematics 0.179, vocational education –0.080, English –0.420.

A major part of the ImpaCT2 project was a study involving 60 schools in England over the period 1999–2002 (Harrison *et al*., 2002), which sought to identify the impact of networked technologies on the school and out-of-school environment, and how these affected the educational attainments of pupils at Key Stages 2, 3 and 4. At both Key Stage 3 and Key Stage 4, statistically significant positive associations between the level of ICT use and attainment were found for science, and the enhanced performance approximated to an increase of 0.56 of a GCSE grade in science. The study focussed 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 science attainment or achievement 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 specific topics have found no difference in learning gains (eg Bezanilla and Ogborn, 1992; Crosier *et al*., 2000.) Some of these studies were designed to evaluate specific pieces of software (eg 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 (Bell *et al*., 1998; Bell, 2003) have tended to concentrate on the practical implementation issues rather than considering the evidence for learning gain. Other writers have focused on comparing learning gains with 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 (Davelsbergh *et al*., 2000) took longer to learn how to use the software than they would have done to achieve the learning outcomes without it. 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

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increased, but there were no real indications that the use of email enhanced science learning. 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 (Cox, 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' abilities 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 the pupils who had not using 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 (students 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 students in the (re)construction of meaning.

Work done by Webb (1992) measuring the strategies of primary pupils building qualitative models with educational modelling software, showed that they learnt logical strategies for categorising science processes and could construct relevant and reliable models. Three 10th-grade classes in Israel 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 students 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 using computer simulations on students' ability to apply their knowledge of the growth curve of microorganisms. The use of computer simulations was integrated as short episodes in the existing biology curriculum. The post-test results on academic achievement indicated that students in the experimental group achieved significantly higher mean scores than the control group. The suggestion here is that students are performing at higher cognitive levels for two reasons.

- They are able to carry out more investigations more quickly and focus on their analysis and hypothesising.
- Collaboration enabled students to exchange ideas and compare results.

Studies have shown the value of simulations for enabling visualisation and hence helping students to solve problems. Monaghan and Clement (1999) analysed think-aloud interview protocols from three high school students 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 help a student make appropriate mental simulations offline in related target problems. Barnea and Dori (1999) conducted an experimental study with three 10th-grade classes who used a discovery approach based on computerised molecular modelling, which enabled animation of three-dimensional representations of molecules of any size and colour in a number of presentation styles. Students in the experimental group performed better than control group students on their spatial ability, understanding of new concepts related to geometric and symbolic representations, and perception of the model concept. Students in the experimental group scored higher than students in the control group in the achievement test on structure and bonding.

Dori and Barak (2001) conducted an experimental study using a new teaching method that combines two types of three-dimensional molecular models: physical (plastic) and virtual (computerised). The research, based on 276 students from nine high schools in Haifa and the northern part of Israel showed that students in the experimental study gained a better understanding of the model concept and were more capable of defining and implementing new concepts, such as isomerism and functional group. They were better capable of mentally traversing across four understanding levels in chemistry: symbol, macroscopic, microscopic and process. Students in the experimental group were more capable of applying

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transformation from two-dimensional representations of molecules, provided by either a symbolic or a structural formula, to three-dimensional representations, a drawing of a model, and vice versa. An interesting finding was that students of a low academic level in the experimental study expressed their explanation graphically.

Trindade *et al*. (2002) in a study of 20 first-year university students, found indications that 3-D virtual environments may help students 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 3-D perception) were shown to be relevant, and only for some topics.

Henderson *et al*. (2000b) investigated whether young students (seven years old) learnt content and concepts embedded in a science computer micro world simulation 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 students 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 to address specific alternative conceptions.

Tao and Gunstone (1999) investigated the use of computer simulations integrated into 10 weeks' physics instruction of a class in a Melbourne high school. The simulations were specifically developed to confront students' alternative conceptions in mechanics. During the instruction process, students complemented and built on each other's ideas and incrementally reached shared understandings. Students' conversational interactions showed that this led to conceptual change.

Jimoyiannis (2001) extended theoretical instruction with the use of simulations in physics teaching aimed to help the transformation of students' alternative conceptions. In this study, two groups (control and experimental) of 90 15- to 16-year-old students 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 students 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 students' understanding at both primary and secondary levels, possibly by:

- 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 students' 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. The importance of real-time graphing for supporting pupils' understanding was supported by a three-month study using data logging in several areas of science by Mokros and Tinker (1987) (in Barton, 1997). This was further supported by an experimental study by Brasell (1985) of distance–time graphing of pupils' movements, in which even a short delay in presenting the graph was sufficient to lose all benefit, evident when the graph was presented at the same time as the pupils moved.

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

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shown no difference in students' understanding using traditional manual data recording and automated data-collecting systems (Striley Stein *et al*., 1990).

Linn and Hsi (2000) found that students were much better at interpreting the findings of their experiments when they used real-time data collection than when they constructed their own graphs. Students' understanding of time-dependent graphs was enhanced even in topics that they had not studied before. For example, students 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 students 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 using common cognitive errors, and evaluated the impact of using computer-based laboratories on the development of these skills among 277 ninth-grade students in one high school. The pupils took part in either a computer exercise or an equivalent paper-and-pencil role-playing exercise requiring them to evaluate the possible eruption of a volcano. Students who used the computer exercise made more consistent decisions than those who used the traditional paper-and-pencil exercise.

There is limited research into students' learning experiences while creating their own educational multimedia applications on science topics. Kafai *et al*. (1997) presented and discussed the results of a project in which seven teams of elementary school students (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, although 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 student research projects and argued that they provided a valuable opportunity for secondary school students 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 students' attainment or achievement in any measurable way.

Distance education at school level may be valuable for particular students or those in special circumstances. Scanlon *et al*. (2002), in a review of technology-mediated practical work, concluded that collaboration at a distance can be successful. Their study was focused on the needs of higher education where distance education is necessary, but they also reviewed studies at school level. They outlined a number of projects around the globe, including five aimed at school level, which offered remote experimentation. They commented, however, that as yet information on most projects is limited, and the learning experiences that the systems enable is unclear. They commented that these projects will be worth following up as they publish their reports, but it was not possible within the time-scale of this research to do so.

Stork *et al*. (1999) reported on the KidSat project, involving collaboration among middle school, high school, and university students with scientists, engineers, teachers and educational theorists to create a programme supported by NASA, the National Science Foundation, 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 from the Institute for the Academic Advancement of Youth observed substantial improvement with regard to students' in-class performance, motivation, and interest in earth and space exploration.

McKinnon and Nolan (2000) studied distinction courses for secondary-aged gifted and talented students, and they 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 in this paper through vignettes about successful students and how their projects developed and how they were supported to achieve work of a very high standard. For example, a 17-year-old student demonstrated the

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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 provide evidence of its effects on attainment or achievement (see for example Michel *et al*., 1999). Reid (2002) in an evaluation of a pilot study of digital video in 50 schools from across the UK, reported teachers' comments that filming 'forces', and editing this into a piece of video, helped pupils assimilate scientific concepts more effectively, quickly and substantially than would have been achieved with handouts or textbooks.

The Computer as Learning Partner collaboration at the University of California (Linn and His, 2000) was a longitudinal study that developed a curriculum and associated pedagogy for a semester-long science course that aimed to integrate appropriate 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 students, 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, as 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, and make predictions online and compare them with the outcomes of their experiments. The design of the Computer as Learning Partner curriculum focused on guiding the process of connecting, linking and reorganising so that students could concentrate on thinking about their experiences in productive ways.

Other long-term studies of the implementation of technology in secondary science classrooms are associated with the Canada-based Technology-Enhanced Secondary Science Instruction (TESSI) project, (Pedretti *et al*., 1998; Mayer-Smith *et al*., 2000). The 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 were increased because students found the approach more interesting than traditional science classes, but attainment of TESSI students as measured by provincial examination scores was at, or slightly below, that of other students. Pedretti (1998) reported that TESSI students were able to offer explicit examples of how technology had an impact on their learning. For example, 64 per cent of the interviewed students 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 students did focus on the benefits of simulations, the vast majority spoke about laboratories and technology as complementary to one another, both playing a role in enhancing learning. TESSI students were also able to discuss meta-learning issues: they spoke about learning to learn, learning responsibility, independence, self-reliance and problem solving. Mayer-Smith *et al*. (2000) reported from the TESSI project that sound pedagogical practices and social organisation in technology-enhanced secondary science classrooms can promote a more equal environment for pupils of both sexes, where students of both sexes participate and perform equally well.

Of interest is whether ICT-based simulations can substitute for experiences in a museum or learning centre, and to what extent this is possible. Baxter and Preece (2000) found that the learning of 48 pupils in years 5 and 6 (9- and 10-year-olds) when taught with the aid of computer planetaria was equally as effective as when pupils were taught with dome planetaria. In this case, ICT has not revealed any increased achievement over the probably preferred alternative of a real planetarium but it does provide the opportunity for pupils who may not be able to travel to such a facility to have similar learning opportunities.

6.2.2.3.1 The effects of ICT on science attainment – conclusions

It is clear from the evidence above that ICT has had a positive effect on many areas of science attainment. Research in the area of science education has included studies of pupils' misconceptions and alternative frameworks for over 40 years, so there is a large body of knowledge about what kinds of misconceptions learners have and what kinds of teaching methods and resources have been found to help address such

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misconceptions (see for example Monk and Osborne, 2000). This has enabled developers and researchers to produce educational software which addresses these learning difficulties. What is also apparent from the evidence presented here is that, unlike in English teaching, the types of ICT use are much more closely related to specific concepts and skills; ICT use tends to be more subject specific than the use of word processing.

Because of the content-and-process nature of many of the ICT environments reported here, it is more straightforward to devise instruments to measure the effects on attainment. Many researchers have devised measures which relate to the specific learner interactions and tasks promoted by a simulation or a modelling environment, and are therefore able to measure more reliably the effects of ICT use. There is evidence of a positive effect of specific ICT uses on pupils at all key stages, which is related to their conceptual development in science and the types of learning environment 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 the pupils.

6.2.2.4 ICT in ICT subject lessons

It is often forgotten that the way in which ICT is used in ICT/IT lessons will also affect the experiences of the pupils, and therefore possibly the way they learn and their subsequent levels of attainment. Although not many national studies in the UK have yet been conducted 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.

First, an underlying problem with the teaching of ICT as a subject is that it is not well taught in the majority of schools. A recent study by Preston *et al*. (2000) of over 100 IT co-ordinators in England, found that less than 10 per cent of the IT teachers were using anything other than word processing more frequently than once a month, even though the requirements of the ICT curriculum include that pupils use ICT to communicate and handle information, explore and develop models of real or imaginary situations, and measure and control physical variables, as well as make judgements about the application and importance of information technology (DES, 1990).

The national ICT requirements therefore include using simulations, building computer-based models, analysing data, measuring and controlling experiments, and communicating information. The positive effects of simulations on learning in science have been discussed in the science section above and there is much research 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, ie 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 students' understanding of different representations has shown that the learner needs to understand the metaphors and symbolisms (Mellar *et al*., 1994). The way in which new technologies have changed the representation and codifying of knowledge, and the way in which this relates to learners' mental models, has enabled learners to develop new ways of reasoning and hypothesising their own and new knowledge. The extent of this difference 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 covers topics ranging from artificial intelligence research into the interpretation of diagrammatic representations (eg Cheng, Lowe and Scaife, 2001) to research into learners' 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 commercial 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

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application, the learner needs to understand the relationship between mathematical equations and tabular means of presenting and inserting these. In the case of the 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 students' performance on two parallel logical reasoning tasks related to database searches (Bezanilla and Ogborn, 1992). Students 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 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 pupils' ability to sort and group chemical data by common chemical characteristics. They tested two pairs of experimental and control classes of pupils aged twelve to thirteen 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 analysing 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 and conduct combined operations, whereas only a few of the control group pupils could reach this level of attainment. Another interesting finding was that the experimental group could sort data which had a specific unique characteristic, eg melt in water, but they could not sort data in ascending or descending order when this 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.

6.2.2.4.1 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, their ability to construct complex models and their understanding of the value of different ICT systems. Clearly the subject of ICT is a special case because it is essential pupils' practical skills are developed as well as their theoretical knowledge. The research shows that if teachers provided opportunities for pupils to carry out in-depth investigations with appropriate modelling environments, then they could reach higher levels of abstraction and competency in the field of ICT.

6.2.2.5 Effects of ICT on modern foreign languages

The field of research into modern foreign languages education includes that 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. Other research papers (Leh, 1999; Tzortzidou and Hassapis, 2001) have also discussed the role of ICT in modern foreign languages, but not conducted significant research on the effects on pupils' attainment.

A French ethnographic study by Carel (1999) found that pragmatic awareness could be developed in virtual contact situations. Some writers have been more moderate in the claims they have made for ICT. Discussing the requirements for initial teacher education, the lecturers for the Postgraduate Certificate of Education at one university (Barnes and Murray, 1999) saw a place for ICT within modern foreign languages, but only within a repertoire of alternative resources. At Trinity College, Dublin, multi-user dungeons[10] and object-oriented multi-user dungeons[11] have been used to support the teaching of the German language (Schwienhorst, 1999), but further research needs to be done in this area.

[10] A multi-user dungeon (MUD) is a software program that accepts 'connections' from multiple users across some kind of network (e.g. telephone lines or the internet) and provides each user with access to a shared database of 'rooms', 'exits' and other objects.

[11] The definition of an object-oriented multi-user dungeon (MOO) comes from MUDs, which were the first text-only multi-user virtual environments on the net. A MOO differs from a MUD, however, in that its purpose is not just game oriented. A MOO is both a database and a programming language. The word 'object' refers to virtual objects that can be programmed into the virtual community, which range from rainforests, to pool tables to Scrabble boards.

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6.2.2.6 ICT in humanities

For this report, humanities incorporates both history and geography because there is less evidence from the literature about the effects on attainment in these subjects than for the other foundation subjects. There is, however, a lot of evidence to show how ICT can be used in both history and geography, especially at Key Stages 3 and 4 (eg Watson, 1993). This use of ICT involves role-playing games, simulations, databases and internet searches.

History

A number of researchers have considered the role of ICT in history (Copeland, 1991; Wolfrum, 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 the Harry Potter books with the historical murder of the princes in the tower (Nichol *et al*., 2003) reported that ICT use did enhance students' learning. Outcomes were broadly similar to previous uses of similar, but card-based, activities, but the introduction of ICT as the carrier medium 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 students' abilities to organise argumentation in writing after using computers for this purpose, but further research showed that this improvement was not transferred into 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 were observed teaching 20 classes of secondary school students. All taught the same historical unit, but selected different units to teach. Three of the teachers received training in the methods of enquiry teaching, the other three taught in a traditional way. While the results of the study suggested that the support of computers might be beneficial to the success of enquiry teaching, they indicated that such support may not be sufficient in the absence of sufficient teacher preparation because curriculum materials are not 'teacher proof' (Copeland, 1991, p. 452). Despite this, it was found that the presence of computer programs enabled properly prepared teachers to teach in a way they would not do 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, although the actual integrated use of ICT in geography was very patchy across the 2,300 students in the study. Most of the positive evidence was provided by the case studies. There were no reported uses of ICT in geography among the primary schools. However, some of the results at secondary level showed clear evidence of improved geographical skills among pupils who used software packages to study geographical underdevelopment, indicators for development, and the relationships between geographical indicators. The other packages used were three general-purpose publishing programs to help in the preparation of GCSE course work. The highly positive results for the 14–16 age groups '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.' (Watson, 1993, p. 139.)

The results in a more recent study showed that students who used multimedia learning environments in geography were observed as 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 students' 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 question, coded by the researchers as 'reproduction' and 'transfer'. 'During the review the students suggested and also invented a lot of relationships between variables, which are part of the model behind the program...The post-test reveals that students in the exploration condition produce more arguments to

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explain their solutions to the transfer questions than the students in the explanation condition.' (Beishuizen, 1992, p.113)

6.2.2.6.1 The effects of ICT on the humanities – conclusions

Although there is less research reported here about ICT in the humanities, there is evidence to show that using simulations can enhance students' reasoning and decision-making and enquiry skills. There was also evidence of ICT enhancing 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, and clearly this is an area of the curriculum where more ICT use and research is needed.

6.2.2.7 The effects of ICT on art

One of the few research studies to consider the role of ICT in art (Rennels and Taylor, 2001) described the use of a database of digital images in 12 classrooms. A number of case studies have been published, and many of these have been of high quality, even if they have not been research-based in a traditional sense. Topics have included the potential of ICT for disabled students of art (Nicholls, 1997), and the potential of digital imaging (Shaikh and Abbott, 2003). In his publication, Nicholls identified key areas where the use of graphic imaging use 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, on the other hand, described a project based in primary schools in Bradford and mediated by him through his role at the National Museum for Film, Photography and Television. The project investigated the potential of digital imagery for helping pupils explore aspects of the built environment in which they live. Through the use of digital cameras, pupils were enabled to expand their horizons, think again about their everyday surroundings and reformulate the images they produced.

6.2.2.8 The effects of ICT on business studies

Until recently, the DfES/DfEE included in its surveys the use of ICT in business studies (DfEE, 2000). This use has been consistently high because of the emphasis on ICT skills in this subject. However, many schools are now combining the teaching of business studies with ICT, which has a detrimental effect on ICT as a subject, but does provide the means for measuring the effects of ICT on pupils' attainment in business studies. However, little research has been published about this except reports of the scores which pupils achieve at GCSE and for the European Computer Driving Licence tests. Discussion of the teaching of business studies has sometimes included an examination of the role of ICT (MacKinnon and Vibert, 2002), self-evident although this may seem.

6.2.2.9 The effects of ICT on physical education

The year 2000 survey of ICT use in schools (DfEE, 2000) for teachers of physical education showed that teachers were making little or no use of ICT, with no teachers making substantial use of ICT. In this literature search no papers were found reporting research into this area, although it is possible that some may be published in lesser-known journals. More attention was given to the use of ICT within physical education when this became a compulsory requirement within the UK curriculum, and some research papers (Cunningham *et al*., 1998) indicate the potential within this area.

6.2.2.10 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 ICT hardware – such as laptops, PDAs (personal digital assistants) and whiteboards – and the use of the internet for seeking and providing information.

The study conducted by Nikolopoulou and Cox (1997), which was discussed earlier (p.42), 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 use the internet to conduct focused and relevant searches.

The use of laptops is 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 any measurable differences are conditional on contextual features and are unrelated to the technology itself. Such features

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may include changing pedagogical approaches, the need for a student-centred environment, and the need 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 student achievement or changes to classroom environments will be reported.' (Boyd, 2002, p30.)

6.3 Research evidence relating to specific social characteristics

There has been considerable evidence published (Shashaani, 1994; Woodrow, 1994; Spender, 1995) on gender differences in the use of ICT for learning. 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 students studying molecular chemistry. A second Israeli paper (Nachmias *et al*., 2001) also found considerable gender difference in ICT skills, with boys consistently more able in their use of applications, but 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 and encouraged in the home.

A UK-based team working with students from years 9 and 10 (ages 13–14 and 14–15) found more evidence of ICT-based learning on the part of the girls than for the boys. (Baxter and Preece, 2000).

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 students in one school 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 (Nachmias *et al*., 2000). Another Israeli project (Passig and Levin, 2001) showed that young boys responded more successfully to multimedia tools when using a games interface.

A key text on gender and ICT (Spender, 1995) also includes data related to an early project which put laptop computers into a girls' school in Australia. The author argued for the existence of a response to ICT that is intrinsically different for males and females. Also in Australia, and located within a Catholic girls school, a different gender-based study (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 increased 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 state of affairs, with one project (Edwards *et al*., 1997) using female tutors to train a class in Logo. Other gender-related research has looked at programming within further or higher education or within adult education (Massoud, 1991). Even where these studies have shown potential for enhancing achievement, it is difficult to be sure of the extent of the applicability to school-based learning and young people.

An early study of the use of ICT to support comprehension (Rice, 1994) showed no difference in the test scores of the group using computers or those that did not, and yet, interestingly, it was found that the two groups were using different strategies when approaching the task.

A Nordic study (Busch, 1995) investigated gender differences regarding computer attitudes and perceived self-efficacy in the use of computers among 147 college students at a compulsory computer course at a Norwegian college. A post-course questionnaire revealed gender differences in favour of males in perceived self-efficacy regarding completion of complex tasks using both word-processing and spreadsheet software. The researchers reported no gender differences in completing simpler tasks. They also found that male students 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.

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At around the same time, another US study (Corston and Colman, 1996) of undergraduates of a wide range of ages found that female students were more likely to succeed if they were working in an all-female group rather than alone or with male students. Overall, however, males performed slightly more effectively on the task set.

Similarly, it has been shown (Harrison *et al*., 1992) 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. The main performance measures in the study included speed of operation. 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.' (Harrison *et al*., 1992, p.205.) It seems likely that the position will by now have changed considerably, but it would take a study of a similar research design to show this incontrovertibly.

Wider discussions of societal change have focused on ICT's place within the new work order (Neill, 1995) and on conceptualising a linked phenomenon, the new communicative order (Snyder, 1992; Snyder, 1997; Snyder, 1998; Snyder, 2002). Similar topics are raised by researchers from Belgium (Soetaert and Bonamie, 1999). Identity, a concept linked to that of online representation and community, has been a key focus for some writers (Rheingold, 1993; Turkle, 1996; Tapscott, 1998).

6.4 Evidence relating to factors which will influence the learning outcomes

A key measure in use by many policy makers seeking to establish the availability and penetration of ICT has been that of the pupil to computer ratio – the number of pupils that exist in an establishment compared to the number of available computers. Although this can be a simplistic and misleading measure, it is one that has persisted throughout the history of ICT use in education, particularly in England where such measures have been collected nationally on a yearly basis (DfES, 2002), so that both summative and trend-based data is available.

In the USA, one study (Alspaugh, 1999) compared 20 schools with different pupil : computer ratios and covering four school districts. Paradoxically, however, Alspaugh sought not to measure the effectiveness of IT for increasing attainment, but to find out whether computers based in classrooms were not in themselves serving as a distraction from other curriculum areas. It should be noted that he found no such effect to be the case, but neither did he find greater achievement in the more IT-rich schools. Alspaugh also ponders whether there might be 'desirable educational outcomes associated with the use of computers that can be identified and measured that are beyond the traditional educational outcome measures?' (Alspaugh, 1999, p.149.)

Other research has sought to clarify the factors that enable ICT to support learning successfully in school classrooms (Teo and Wei, 2001; Thomas, 2001). Interest groups such as the British Computer Society have published policy documents (Passey, 1998) addressing this area, as has the Society of Information Technology Management (SOCITM, 2002). A number of studies (Cornu, 1995; Watkins and Mortimore, 1999; Banks *et al*., 1999; Dawes, 1999) have included a consideration of IT or ICT within a wider discussion of pedagogy or achievement, or raise issues that throw light upon the use of ICT. One example (Alexander, 1992) makes clear the necessity of examining teachers' beliefs and practices as the only way of fully understanding the effectiveness of IT in the classroom. Another, from Germany (Bromme, 1995), considers pedagogical knowledge as part of the professional 'knowing and doing' of teachers, and a study of ICT pedagogies in Malaysia (Cloke and Sharif, 2001) is used to throw light upon UK practices. Several studies (Gibson, 1996; Gibson, 2001) support the call for a more informed and debated pedagogy for ICT, and the Palm project sought to present a model for it (Somekh and Davies, 1991).

A recent literature review considered a range of factors inhibiting ICT use in schools (Mumtaz, 2000). Some studies (Fabfy and Higgs, 1997) have considered in particular the barriers that stop schools from making effective use of ICT, including teachers' beliefs (Fang, 1996; Gobbo and Girardi, 2001). One academic paper produced as part of the US Teaching, Learning and Computing project (Becker *et al*., 1999) studied 21 teachers from six schools that were among the first to participate in the Co-NECT Schools programme of whole-school, technology-infused reform. The report suggests that these technology-aware teachers have pedagogical styles that differ from others, and that the Co-NECT schools

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themselves function differently from other environments for teaching. Another study (Fishman and Packard, 2001) suggests that it is the lack of access to an appropriate planning tool that causes problems for teachers.

A large-scale quantitative study in Birmingham (Mosely, 1999; Moseley *et al*., 1999) based its methodology on the Teacher Training Agency's definitions of ICT, and identified a range of factors for teachers to take into account when using ICT to improve attainment. These included clearly identifying how ICT will be used to meet specific objectives, ensuring pupils have adequate ICT skills, and matching pedagogy with the intended objectives and outcomes.

A more recent study (Baylor and Ritchie, 2002) of 94 classes across four different states in the USA considered the impact of seven factors related to school technology (planning, leadership, curriculum alignment, professional development, technology use, teachers' openness to change, and teachers' non-school computer use) and applied these to five dependent measures in the areas of teachers' skills (technology competency and technology integration), teachers' morale, and perceived student learning (impact on students' acquisition of content and higher-order thinking skills). As a result of this exercise, the team suggested a series of predictors (teachers' openness to change etc) that may suggest success in particular uses of ICT. The schools chosen were known high-technology institutions, and the researchers argued for a use of ICT which is broadly constructivist and collaborative in nature. However, a weakness of the research was the adoption of teacher perception rather than standardised scores as a measure of student attainment. A Dutch study (van Braak, 2001) also provided evidence for pedagogical awareness increasing where teachers' ICT capability is advanced.

A study of 438 teachers in 152 early-adopter internet-using schools in the USA (Becker and Ravitz, 1998) considered the extent to which social class was a factor inhibiting students accessing online resources. Some differences were noted according to socio-economic factors, but bigger variations were noted with different topics of study (with subjects such as media, social studies and science showing higher levels of use) and different levels of prior achievement of students.

The use of the internet within ICT lessons has led to a significant body of research (Kumari, 1998; Carroll, 1999; Crump, 1999; Crystal, 2001), but much of this has been related to university students rather than school students.

Consideration of curriculum development in ICT has sometimes been both thoughtful and rigorous (Grey, 1999) providing some clear pointers for future research, and has often been far-sighted, as in Squires' proposal for the peripatetic electronic teacher (Squires, 1999), which is now at least being partly developed in the UK, through the establishment of learning mentors.

Much of the research related to computer-mediated communication has been focused on asynchronous communication but, as connectivity speeds increase and recreational practices are brought into the classroom, synchronous communication (such as real-time chat) is becoming a feature in the literature (Ingram *et al*., 2000). It has become clear that managing computer-mediated communication is a complex task for which training is needed (McLoughlin and Oliver, 1999). Use of computer-mediated communication also leads to a re-examination of student-centred or teacher-centred practices (Moss, 2002).

Many researchers (Bohlin and Hunt, 1995; Knezek and Christensen, 2002) have seen the education of teachers as a vital area to address if ICT is to fulfil its potential. Major programmes of training for teachers, such as have taken place in the UK through the New Opportunities Fund programme, have helped to raise teachers' confidence levels (Ross *et al*., 1999), and other models have been developed with similar aims (Wiburg *et al*., 1999). In Scotland, a key challenge has been seen as the need to develop learner-centred pedagogies in ICT (Simpson *et al*., 1998). In the USA, by contrast, teachers still see lack of training (Guha, 2001) as a barrier to their effective use of ICT in their teaching. Styles of assessment within ICT as a subject, and when ICT is used within other subjects, tend to veer towards the summative. More recent understandings (Black and Wiliam, 1998; Black and Wiliam, 2002) of the potential of formative assessment have yet to affect practice in this area to any great extent.

Other research papers (Hung and Wong, 2000) have raised different aspects of the pedagogy of ICT, including attitude–behaviour theory (Levine and Donitsa-Schmidt, 1997). Some ICT research is now

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drawing on more established methodologies which have been used for other innovations in education (Loucks *et al*., 1998). Attention has been paid recently to the learning outcomes linked to the use of computer games (Rosas *et al*., 2003), by which is meant recreational games rather than the educational software games of previous years. A DfES-funded exploration of this area sought to investigate the contribution that games might make to the educational process. The project report (McFarlane *et al*., 2002) discussed the perceived mismatch between games content and curriculum content, seeing this as a missed opportunity for skills recognition. Teachers were reported to be broadly supportive of the notion of integrating games skills into the curriculum, but it is difficult to see how this might happen within the current rigid UK framework.

6.5 Qualitative studies and case studies

The literature review has provided very many case studies into the effects of ICT on attainment. Hennesey *et al*. (2003) investigated a group of 115 teacher researchers across a wide range of settings. This particular study found significant evidence for a change in teachers' roles leading to greater control by students of the learning process, with teachers providing less direction and exposition.

Over the last 10 years a large number of books and papers have been published that deal with the use of ICT in particular subjects. These have varied from specific case studies of individual teachers and their pedagogical practices (Masters and Yelland, 2002) to large-scale ethnographic studies. A key factor running throughout many of the papers is the need to develop and refine pedagogical practices (Shulman, 1987).

The area of literacy/English is one where much has been published, with a growing body of material now available dealing with many aspects of the use of ICT for communication and literacy. 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 homepages (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, which has extended the specification of knowledge and knowledge domains that learners now meet in education (Anderson, 1978; Merrill, 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 literacies 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, during which teachers reported that this technology had helped pupils assimilate and understand concepts (Reid *et al*., 2002). In this case, the findings were based on teachers' perceptions rather than test scores.

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

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6.6 The ways in which ICT use relates to the ICT resource and learners' attainment

It is essential that software design is underpinned by a clear understanding of pedagogy (Hinostroza and Mellar, 2001), although this has not always been the case in practice (Squires and McDougall, 1994). It has also often been the case that ICT resources have not been fully attuned to the particular needs of the students for which they are intended (Holmes and Russell, 1999). Changing notions of literacy and changing literacy practices have been reflected in particular by writing related to developing pedagogies of ICT (Loveless, 2000; Loveless, 2002; Loveless and Ellis, 2001; McDiarmid, 2002). Creativity has begun to feature in the literature (Abbott *et al*., 2001; Loveless, 2002), although it does not seem to have major prominence in the UK curriculum at present.

6.7 The different aspects of learning promoted by ICT use

Students can be perceptive about their own learning with ICT (Irvine and Barlow, 1998), and this is the focus of a paper by a Canadian ICT teacher and researcher (Bout and Mcnay, 2002). The paper suggests that, given the opportunity, students are very able to engage in meta-cognitive discussion of their own learning.

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

The development of interest in constructivist views of learning has led to papers concerned with establishing the implications of such views for ICT (Leask and Younie, 2001; Scrimshaw, 2001).

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[12] rather than a cognitive conflict[13] explanation of the learning process. This study is similar to past reviews in showing a learning advantage for computer-aided instruction, but the authors contend that 'this gain in proficiency is an artifact of poor research design and comes about because of the superior quality of computer-aided instruction materials, rather than some intrinsic aspects of computers, *per se*, as vehicles of instruction.' (Eraut, 1995, p. 231.)

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 practice was reported to have provided considerable support to students 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.' (Peters, 1996, 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 internalising of cognitive skills as a result of such collaborative activities.

Other factors within and outside schools can modify the effectiveness of teachers using ICT, as has been shown in a number of papers (Yaghi, 1996; Yaghi, 1997; Yaghi, 2001). A revival of interest in whole-class teaching in the UK has led to a rapid uptake of didactic tools such as interactive whiteboards, themselves foreshadowed in the literature (Stromme, 1998), and the beginnings of a research literature related to their use (Glover and Miller, 2001). Critical analyses of ICT use in classrooms (Healy, 1998) have had a role to play too.

[12] Vygotsky's sociocognitive 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.

[13] Piaget argued that cognitive conflict is the principal 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.

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6.8 The use of ICT in informal settings

Much has been made in some writings (Dery, 1994; Baym, 1995) of the potential that online groupings may hold for building productive and mutually beneficial communities (Rheingold, 1993; Tweddle *et al*., 2000). Some of these communities have learning as a central goal (Gallini and Zhang, 1997; Schell, 2001; Hertz-Lazarowitz and Bar-Natan, 2002; Schrum and Hong, 2002; Stacey, 2002). Other communities may not be focused on learning, except in the widest sense, but they have often been characterised by shared common purposes (Mitchell *et al*., 2001), mutual support mechanisms, learner autonomy (Zandvliet and Straker, 2001) and outcomes leading to group approbation.

Although the edited works of Steven Jones, for example, contain discussions of adult learning communities (Baym, 1995), the outcomes described may not apply to young people. Similarly, the range of learning styles found in one project (Shaw and Marlow, 1999) may relate specifically to undergraduates rather than to learners in schools, whereas another project (Susman, 1998) found that the effect of co-operative online communities was greater where the learners were children than when they were adults. 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 were previously used to in their classrooms.

Discussions of the evaluation of online courses for teachers (Benigno and Trentin, 2000) and the use of online learning within higher education (Tearle *et al*., 1998) offer more specific pointers to effective use of ICT in these environments, as does the description (Curran, 2002) of an internet-based planning tool. New pedagogies are needed here, although some may be based on existing models such as the music master-class (Ruhleder and Twidale, 2000).

Much of this writing fits within an overall approach which could be described as that of social geography, with 'online' being seen as a place in a much more real sense than has previously been the case. First to coin the phrase 'post-geographical' (Negroponte, 1995), Nicholas Negroponte has opened the way to a variety of researchers who have taken similar approaches, from Tapscott's N-generation (Tapscott, 1998) to the Cyberkids described by Gill Valentine and her co-researchers (Valentine and Holloway, 2002). The Media Lab at MIT, and especially the constructionism team led by Seymour Papert, continue to be influential, as do seminal works from this team (Papert, 1998).

Informal settings have not only been online. Her Majesty's Inspectorate noted in the early 1990s (HMI, 1992) that there were clear issues to be considered when placing ICT resources into museums, for example, or when planning the use of ICT resources in association with a museum visit. A key factor for success was found to be the extent to which teachers and museum staff had been able to plan together the nature and dimensions of the task to be set to pupils.

6.9 Attitudes of students towards ICT-linked innovation

There are many claims made in the media of the effects of ICT on pupils' motivation, and much of the UK research evidence about ICT and motivation has been reported in the mainstream publications on ICT in education, and in official research reports (eg Watson, 1993; Gardner *et al*., 1993; Cox, 1997; Cox, 1999a). Ever since the early days of using small microcomputers, there have been reports of pupils staying longer on the task, increasing their commitment to learning, achieving more through the use of computers and of being enthusiastic about using computers in their lessons.

It is now well known that the use of word processing can lead to improvements in written composition skills and other literacy skills as explained earlier (eg Hartley, 1992), but it is also clear from many research studies that by providing pupils with the opportunity to improve their writing and presentation skills, this 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:

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> "*They are more willing to spend more time completing pieces of work, working through lunch-times, after school, and on homework. Their work is better presented and this has resulted in much more of their work being used for display purposes*."
>
> Secondary school teacher (Stradling *et al*., 1994 p.15)

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 the learning tasks. In a study by Cox (1997) of the opinions of 144 pupils and students about how ICT contributed to their school work, over 70 per cent of the pupils believed that it helped them to achieve a better quality of work:

> "*Computers are very useful machines. You can set out and present your work very well. You can type up essays and other information. When a mistake is made you can go back and delete the mistake or amend your document unlike typewriters where you have to use Tippex*."
>
> Female secondary school student – aged 13 (Cox, 1997 p.17)

Similar evidence for an increased commitment to the learning task was found by the first ImpacT project (Watson, 1993). The project investigated the impact of ICT on children's learning. The research team studied 87 classes of pupils aged 8–10, 12–14 and 14–16 over a period of two years. Results from pupils' interviews and from observations of them showed that their commitment to their work was enhanced by the use of ICT. The following example is just one of many showing this increased commitment:

> "*Interviews about using computers for illustrations and graphs frequently elicited the response 'It is neat...it looks better...the graphs are more accurate.'...The teacher explicitly encouraged this perception and praised the results*."
>
> Watson (1993) p. 71

The studies referred to above concern pupils that have regular access to word processors, with sufficient time to develop their written work. The same degree of motivation would not arise where pupils have very limited access and no time to reflect on what they have written or to improve it. Given sufficient access for pupils using the internet and CD-ROMS, both of which could aid the production of attractively presented work, then similar motivation is likely to occur. 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 the quality of their presentation, demonstrating an increased commitment to the learning task.

Further examples of pupils' motivation are provided by the studies on the use of integrated learning systems in a number of schools. In a study of the use of two different integrated learning systems in selected classes in four primary schools and eight secondary schools (NCET, 1994), information was collected through pupil questionnaires about their perceptions of the value of the systems they had been using for six months, as well as interviews with teachers and observations of class use. The researchers found that pupils using the integrated learning systems demonstrated increased commitment and dedication to studying, shown by the higher levels of concentration when using the systems and the lower number of non-task interactions taking place, compared with the pupils not using the integrated learning systems. Even some of the primary pupils even booked extra sessions during their lunch break if they had missed any timetabled sessions. The following comment reflected the views of many of the pupils:

> "*Must go to the computer – I have been thinking about this problem all night and I must get to the computer because I know the answer*."
>
> Secondary student using integrated learning systems (NCET, 1994 p.23)

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 from mathematics to English the attention span was then much longer. However, 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. As one teacher observed:

> "*These kids are doing more in thirty-five minutes than in a whole week of conventional lessons*."
>
> Secondary teacher (NCET, 1994 p.25)

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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 focussed 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.' (Comber *et al*., 2002, p. 9.)

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

7 Theories of innovation and change

We have included a brief review of the relevant theories provided in the literature because they can often inform researchers of the most effective ways of designing relevant procedures to measure the effects of ICT on attainment and pedagogies.

7.1 Theories of behaviour and attitudes towards ICT

Ames (1992), who analysed a number of research studies, developed a theoretical framework for motivation relating to a belief in oneself and the ability of pupils to do better through long-term goals. She considered two types of motivation goals: mastery goals and performance goals, which involve different ways of thinking about oneself. Mastery goals relate to the belief that effort and outcome are interdependent. With such goals there is a motivation to learn by developing new skills, trying to understand the tasks, improving the level of competence and achieving a sense of mastery based on self-referenced standards. Achievement of mastery goals is therefore likely to lead to a longer-term high-quality involvement in learning, compared with achieving performance goals of particular tasks. In the case of ICT this would involve developing competence in performing learning tasks in order to acquire higher skills and more knowledge.

Performance goals on the other hand focus on one's ability and sense of self-worth. 'Especially important to a performance orientation is public recognition that one has done better than others or performed in a superior manner' in achieving specific goals (Ames, 1992). These goals are directed towards achieving success in relation to the achievements of one's colleagues.

Research by Ames (1992) has also shown that 'tasks that involve variety and diversity are more likely to facilitate an interest in learning and mastery orientation. Students are more likely to approach and engage in learning in a manner consistent with a mastery goal when they perceive a meaningful reason for engaging in the activity.' This suggests that if pupils perceive that ICT will help them in their long-term future, they are more likely to spend time on the ICT-based activity and related work. On the other hand, in terms of rewards to motivate pupils, there is considerable research evidence to show that if rewards are perceived merely as short-term bribes, this has an undermining effect, especially if they have little relevance to the activity in question.

Davis, Bagozzi and Warshaw (1989) developed a theory of 'action relating to reasons' (technology acceptance) based on the work of Fishbein and Ajzen (in Davis *et al*, 1989) to investigate the reasons why some people use computers, and their attitudes towards them. Their model, shown in Figure 1.1 below, links the perceived usefulness and ease of use with the attitude towards using ICT and the final use (system use). They tested this model with 107 adult users, who had been using a managerial system for 14 weeks. They found that people's computer use was related to their intention to use computers, and perceived usefulness was also strongly linked to this intention. This supports the discussion above about increased motivation through perceived value of an activity.

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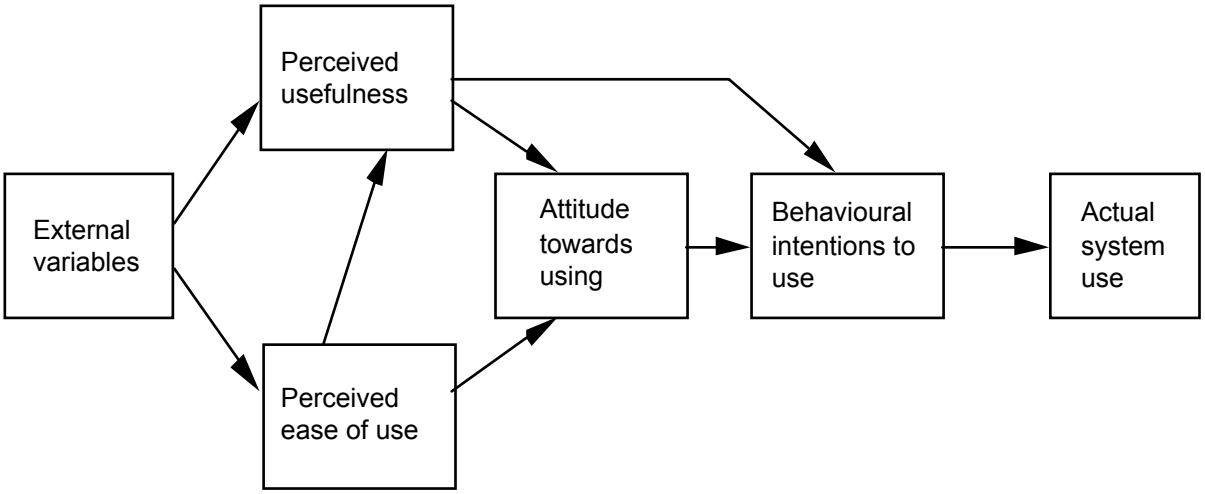

Figure 1.1 – Technology acceptance model (Davis, Bagozzi and Warshaw, 1989)

It is clear from these theories, which have been evaluated through many empirical studies, that the motivational effects of ICT will have an important influence on pupils' attitudes to studying and learning, which in turn has a positive effect on pupils' attainment. It should be noted, however, that these theories only apply if the ICT activity is interesting, challenging and rewarding. There is some evidence from the literature that pupils can tire or become bored with some ICT activities, so like any other teaching method, it should not be assumed that all ICT use will motivate pupils in the ways described above.

7.2 Theories of the application of ICT to education

Perhaps the most prominent body of literature within this area has been that devoted to the transformative effect of ICT on the nature of schooling itself. Although this has been a topic characterised as much by hyperbole as exactitude, and with entrenched opinions easier to find than open minds, more recent texts (Abbott, 2000) have attempted to present a more balanced and progressive view, rather than predicting wholesale change overnight.

One view, while not critical of ICT in itself as a learning technology, is to argue that ICT has not yet found a role within education (Watson, 2001). The nature of ICT as a subject has also been the focus of discussion (Webb, 2002) and many of those active in the field have continued to note the difference between ineffective computer-assisted learning type use of ICT and more transformative approaches (Somekh, 2000). Most recently, critical writings (Cordes and Miller, 2000) have tended to focus on the supposed dampening effects of computers (rather than ICT) on the creativity of young learners. In this way, such critics have built on the pronouncements of previously published sceptics (Postman, 1995), and are at variance with those who seek to increase ICT use in education (Williams and Smith, 1994). The views of the critics have been at least partly refuted through responding journal articles (Abbott *et al*., 2001), although the sceptics continue to raise doubts from an opinion-based rather than research-led perspective (Stoll, 1995; Cuban, 2001). Cuban's views found favour with researchers considering the Scottish perspective (Conlon and Simpson, 2003). They suggested that it is only home use of computers that can be truly educational, with much school-based use insignificant or peripheral to education, although it is perhaps surprising that it is word processing which they give as an example of non-educational use of ICT.

Another recent study of 94 primary pupils in four Midlands schools (McNicol *et al*., 2002) indicated the continuing effects of home, school and locality on the extent and nature of ICT use within education. One of the main overarching findings arising from many of the studies quoted is the essential role of the teacher, and this is also noted in a recent study of primary pupils in Wales (Selwyn and Bullon, 2000). This paper noted the mismatch between what ICT might be used for in classrooms and the ways in which it is actually used. The extent of this varied, out-of-school use of ICT was also seen as important. This has been stated from earlier days (Educational Technology Centre, 1990) and continues to be reiterated until the present. Technologically determinist world views are consistently refuted in favour of informed use of ICT tools by well-trained and perceptive pedagogues.

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Questions remain, however, and it is not only demagogues such as Larry Cuban and Clifford Stoll who are pressing for evidence to support and justify the investment world-wide in educational technology. A group of UK authors in a recent paper (Reynolds *et al*., 2003) reflected on what has been achieved, and noted teachers' continuing beliefs in the value of ICT, but considered this alongside what they see as a paucity of evidence for any real attainment gains which can be incontrovertibly linked to ICT use. They make much of the need for this evidence after 20 years of investment, although this could be considered a mere beginning in terms of the life of delivering technology for learning. We are, after all, still learning about the best ways of using books to support education, and they have been around for 500 years or more.

8 Conclusions

The evidence from our literature review shows a strong relationship between the ways in which ICT has been used and the attainment outcomes. This relationship is dependent upon the teacher's pedagogical practices. The effect of teachers' pedagogical practices is discussed in a separate report (Cox and Webb, 2004), while the focus of this study is on pupils' attainment.

8.1 The research literature

The evidence from the research literature is much more extensive and more reliable in some areas than in others. First there is a more substantial literature base for educational research in science and mathematics into pupils' understanding, alternative conceptions, learning strategies, etc, than there is in the other National Curriculum subjects. Therefore there are more studies of the effects of specific ICT uses on attainment in these subjects.

Secondly, there are many more uses being made of different ICT resources in mathematics, science, ICT and English than there are in other subjects, which is shown by the DfES's surveys and many other surveys over the last 25 years. This means that there are a greater number of ICT resources available to these subject teachers, there is a greater body of knowledge about educational practices for ICT in these subjects, and there is a greater body of evidence of the effects of ICT on these subjects.

Thirdly, the amount of published evidence is greatest for those ICT resources which have been embedded in some teachers' practices for a longer time. There is an emerging body of knowledge about the effects of specific ICT communications such as the use of email or the World Wide Web, but the evidence of the effects on pupils' attainment is not yet extensive for two reasons. The first reason is that these communication resources are not yet widely used in the school curriculum, and the second is that because they are generic by nature, it is more difficult for teachers to think of ways of integrating them into their subject teaching.

As a consequence of the greater body of evidence, the strongest and most substantiated results for the effects of ICT on pupils' attainment are in science, mathematics and English.

NB: The evidence is that specific uses of ICT, such as using simulations in science, modelling in mathematics or word processing in English, have had a positive effect on pupils' learning, but this does not mean that all and/or any ICT application has been shown to have this effect.

8.2 The effects of ICT on attainment

The evidence from the literature shows a positive effect of *specific* uses of ICT (explained below) on pupils' attainment in almost all the National Curriculum subjects, especially mathematics, science and English. Evidence in other subjects has not yet been substantiated by a series of independent studies. For example there is evidence that using computer database software has a positive effect on pupils' learning of information-handling skills, but there are not many studies yet to support this. Studies reported in the literature have identified a range of factors which influence the outcomes of pupils' learning.

8.2.1 The frequency and range of uses of ICT in schools and the home

The evidence shows that there is still a wide range of access to ICT in schools and at home. The DES (1990) / DfEE (1997, 1998, 1999, 2000) / DfES (2001, 2002) surveys have shown that throughout a period of more than 10 years up until 2002, less than 50 per cent of school teachers regularly used ICT in their lessons, and when they did, use of ICT was limited to a few types use, eg using the whiteboard for whole-

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class demonstrations, and using word processing for creative writing. Regular uses reported by teachers may mean only a few minutes of use by individual pupils, or extensive use by some pupils and much less by others. This variation in use affects the possible impact of ICT on pupils' learning.

Access to ICT in the home is helping some pupils continue with homework, share homework ideas through 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 have shown a statistically significant positive effect of ICT on pupils' learning – for example, the ImpacT and ImpaCT2 studies (Watson, 1993; Comber *et al*., 2002; Harrison *et al*., 2002; Somekh *et al*., 2002). However, apart from the mini-studies in the first ImpacT project, it has not been possible to identify the actual types of ICT use which have contributed to these learning gains measured in large quantitative studies. The first ImpacT study used specific instruments that were closely related to the types of learning being promoted by the uses of ICT to enable the researchers to measure the effects of this use 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.

Specific, smaller focused studies have provided substantial evidence of the contribution of specific uses of ICT – such as the use of simulations in science, the use of modelling in science, ICT and mathematics, and the uses of word processing in English – to pupils' learning. 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, this 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 taught 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 still be attributable to the specific ICT uses.

8.2.2 Effects of ICT on mathematics attainment

The evidence shows that there have been positive effects of ICT on pupils' learning of different concepts and skills in mathematics at both primary and secondary levels. These effects are firstly more 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, learning concepts of ratio and proportion. The evidence also shows that learning and attainment are closely related to the learning context, the role of the teacher and the regular integrated use of the ICT application in the curriculum. Evidence gathered through standard national tests, which are not specifically designed to measure new ways of reasoning, hypothesising or expressing knowledge, are less likely to reveal any positive learning gains.

8.2.3 Effects of ICT on English attainment

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 both positive and negative effects of word processing on pupils' learning. The most positive evidence arises from primary pupils' use when they are at the early stages of language development and when they have a chance to compose and reflect on their compositions. One reason for this difference in results is that many teachers, as reported in the literature, are only using word processing for pupils to present their work, even though the greatest potential is for pupils to compose, draft, revise and organise their thinking and writing.

One of the problems with 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

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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, or of composing, interpreting, orating and other skills which might also be affected by the use of ICT in English.

8.2.4 Effects of ICT on science attainment

It is clear from the evidence in this report that ICT has had a positive effect on many areas of science attainment. Science education has included research into pupils' misconceptions and alternative frameworks for over 40 years. Therefore there is a large body of knowledge about what kinds of misconceptions learners have and what kinds of teaching methods and resources have been found to help address such misconceptions (eg Monk and Osborne, 2000). This has enabled developers and researchers to produce educational software which addresses these learning difficulties. What is also evident from the research results presented here is that, unlike English, the types of ICT use 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.

Because of the content-and-process nature of many of the ICT environments reported here, it is also more straightforward to devise instruments to measure the effects on attainment in science. Many researchers have devised measures which relate to the specific learner interactions and tasks promoted by a simulation or a modelling environment, and are therefore able to measure more reliably the effects of ICT use. There is evidence of a positive effect of specific ICT uses on pupils' attainment at all key stages, which is related to their conceptual development in science and the types of learning environments. However, 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 the pupils.

8.2.5 Effects of ICT on ICT attainment

The evidence from the literature has shown that innovative and challenging uses of ICT can improve pupils' data-handling skills, their abilities to construct complex models and their understanding of the value of different ICT systems. Clearly the subject of ICT is a special case because it is essential that pupils' practical skills are developed, as well as their theoretical knowledge. 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 they could reach higher levels of abstraction and competency in the field of ICT.

8.2.6 Effects of ICT on modern foreign languages attainment

The field of research into modern foreign languages education includes that of linguistics and the effects of new technologies. There is evidence of a positive effect of specific software on attainment, such as foreign language simulations. 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 the instruments have measured specific skills closely related to those used through the ICT application.

8.2.7 The effect of ICT on the humanities attainment

Although there is less research reported here about ICT in the humanities, there is evidence to show that the use of simulations can enhance students' reasoning and decision making, and the understanding of historical and geographical processes. 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.

8.2.8 The effect of ICT on art attainment

There are some studies on the effect of the use of ICT on pupils' understanding of digital imagery, but more research needs to be done in this area to substantiate these findings.

8.2.9 The effect of ICT on business studies attainment

Little research has been published about the effects of ICT use in business studies, except for reports of the scores which pupils achieve at GCSE and in the European Computer Driving Licence (ECDL) test.

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These scores are reported to have improved through the regular use of ICT, but more research in this subject is needed to substantiate these findings.

8.2.10 The effect of ICT on physical education attainment

There is little use made of ICT in physical education, so the research evidence in this area is confined to a few case studies and not yet substantial enough to be able to draw any generalised conclusions.

8.3 The effects of ICT on pupils' attitudes and motivation

Many of the research studies claim that ICT can also enhance the attitudes and motivation of the pupils. There are two different methods of measuring attitudes and motivation of pupils, which affect these claims.

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

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

8.4 Evidence relating to factors which will influence attainment

There are a range of factors which have been identified, which will also influence the effect of ICT use on pupils' attainment. Many of these have been mentioned in the subject sections above and are also presented here.

8.4.1 Teachers' pedagogies

Many published studies have shown, as expected, that the teachers' pedagogies have a large impact on pupils' attainment. These are discussed in detail in the separate literature review which investigates ICT pedagogy (Cox and Webb, 2004, pp.18–20), and include:

- the teachers' decision to take up the use of ICT in their teaching
- the types of ICT resources teachers choose to use
- the teachers' knowledge about their own subject
- the teachers' knowledge of the potential for ICT to enhance their pupils' learning
- the teachers' ability to use ICT effectively (ie their ICT skills)
- the teachers' knowledge about how to organise the learning before and during the lessons
- the teachers' ability to integrate ICT into their whole curriculum programme
- the teachers' understanding that ICT environments can promote new kinds of learning and new knowledge
- the teachers' ability to relate the ICT activity to learning goals and objectives
- the teachers' ability to measure relevant learning outcomes.

8.4.2 The use of ICT in different school and home settings

As has been explained above, the effects of ICT on attainment will also be dependent upon the ways in which ICT is used in schools and within specific subjects.

The studies reported here are of two main types: those in which the researchers measure the effects of the ICT uses which teachers have already chosen to use, ie naturalistic studies, and those in which the researchers have introduced a specific ICT resource, eg given the teachers laptop computers. The latter are called intervention studies. In an intervention study, the settings in which the ICT is used as well as the teachers' pedagogical practices are influenced, and this will affect the outcomes recorded.

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8.4.2.1 Naturalistic settings

In naturalistic studies 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 use on pupils' attainment. In secondary schools, most of the research in these studies involves teachers using networks of computers, an electronic whiteboard, or clusters 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 (Cox and Webb, 2004, p. 93). This has the effect of teachers often not providing sufficient structure to the activity, and less structured activities have been shown to be less effective in raising 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.

One approach, which is growing in use by some researchers, is that of action research, in which the teacher (sometimes supported by an external researcher) is the researcher as well as the subject being researched. Some of these studies are naturalistic because the teacher is already using the ICT resource in their teaching. Others may be intervention studies where the teacher has been given an ICT resource and then proceeds to conduct research into its use, and/or where the external researcher takes an active part in helping the teacher use the resource in the classroom. The reporting of action research is often limited by the teacher's inability to write objectively, situating the findings in a wider context. Additionally, teachers often do not have the time to document and publish their research.

In the use of whiteboards for whole-class use, the positive effects on pupils' attainment reported in the literature include making pupils' understanding more overt, and promoting more effective oral expression; it was also reported that the use of whiteboards enabled knowledge to be presented in more varied visual forms. However, the negative effects reported include teachers focusing only on presentation skills and not using ICT effectively to enhance pupils' understanding of the subject.

In primary schools, many studies report using 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 opportunities 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 opportunities to use the computers. Limited computer access is having a serious negative effect on the contributions which ICT could make to, for example, pupils' progress in English and literacy.

8.4.2.2 Intervention studies

We have also reported on many intervention studies in which the research team has provided the ICT resource for a period to examine how its use would affect pupils' learning. Resources have included integrated learning systems, laptop computers for pupils and teachers, electronic whiteboards, and computer-based modelling environments. Some of these have shown a positive effect on pupils' attainment where, as explained earlier, the uses of ICT have been closely related to the aims and objectives of the curriculum and specific concepts and skills.

There are limitations to intervention studies regarding whether the results can be generalised across other school settings and informal settings. For example, when teachers are given laptops this has a large effect on their pedagogical reasoning (Cox and Webb, 2004, p.83) because they have to rethink the way they deliver the curriculum, and may have little understanding of the scope of the resource for teaching and learning. We can see from Section 8.4.1 above and from the pedagogy study (Cox and Webb, 2004) that teachers need a substantial range of skills to be able to use ICT effectively. Therefore, for such intervention studies to be reliable and effective, the teachers need many months preparing for suitable uses of the ICT resource. Alternatively the studies need to be conducted over a long time (two to three years); this would enable the teachers to acquire the necessary pedagogical knowledge and skills to use ICT resources to best effect in their teaching. The 'try it and see' approach to measuring the value of an ICT resource is fraught with problems. What it mainly measures is whether teachers can use the resource in their subject, but it rarely measures if they can use it to best effect.

8.4.2.3 The use of ICT in informal settings

There are research studies which have shown that using ICT in informal settings (home, clubs, etc) can contribute to the learning experiences of pupils, but not many pupils have yet integrated such uses with their school experiences. One of the benefits reported by teachers is that pupils can debate homework

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tasks among their peers, thereby promoting challenges to their own understanding. Similarly they can share their ideas in a chat room, website or through emails to friends and the teacher. 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.

8.5 Research methods to measure ICT and attainment

The strengths and weaknesses of naturalistic and intervention studies were discussed above. In both types of studies a range of instruments have been used, some of which are more likely to measure pupils' attainment than others. 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 use of different ICT environments. 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.

8.5.1 Quality and depth of ICT use

The effects of ICT use are clearly influenced by the quality of the learning experience. There are many research studies reported here in which the researchers show a clear understanding of the educational potential of the ICT resources being used. However, there are some studies in which the researchers themselves do not appear to understand the attributes of the ICT resource, nor the ways in which teachers might use such resources. For example, there is no point in attempting to measure the effects on attainment of using ICT in English and literacy if the only use being made by the teacher is for pupils to type up their hand-written products and print them out. Similarly if a science teacher is mainly using word processing with the pupils to write up assignments, then there is unlikely to be a positive effect on pupils' understanding of science concepts.

It is essential in any study that the actual types of use of ICT are accurately recorded and measured as well as the effects on pupils' attainment. Studies which only record pupils' ICT use, but which do not identify what specific uses occur, cannot subsequently claim any relationship between ICT use and attainment. It is like claiming that books or the blackboard have an effect on learning.

8.5.2 Attainment tests

The evidence of this review has shown that studies are more reliable and provide more robust evidence where the tests have been closely linked to the likely effects of ICT on pupils' learning. For example, if using Logo enhances pupils' geometry and problem-solving skills, then the mathematics tests should focus on measuring these and should not include a range of other mathematical skills. Similarly the use of simulations in science has been shown to help pupils learn difficult science concepts through confronting their own misconceptions and through presenting graphs on the screen. Tests to measure these should closely relate not only to measuring the pupils' learning of those concepts, but also to the graphical interpretations of the relationships between the concepts.

It is possible to measure the effects of ICT on pupils' attainment through large-scale comparative studies, but the design of the tests needs to be based on an extensive knowledge of the types of ICT use being made by the subjects in the study. For example, one might have a large-scale study to measure the effects of using computer-based modelling in science on pupils' understanding of science concepts and on the development of modelling and science reasoning skills. Alternatively, one might have a large-scale study of the effects on a range of subject-related presentation skills of using a whiteboard.

8.5.3 Observations of pupils using ICT

The literature has shown that detailed observations of pupils using ICT and of teachers' classroom practices can reveal pupils' learning strategies, the effects of teacher interventions, etc. This approach provides more in-depth data about the learning experiences of the pupils, which can then be related to measures of learning outcome. Observations employ a range of recording methods. One of the most useful noted from the studies is the use of video to record the actions of pupils and teachers when using ICT. This technique has been used to record the on-screen actions in parallel with the pupils' physical activities, enabling the researcher to analyse the relationship between the two. It is very difficult to gain detailed knowledge of the learning experience without actually observing it taking place.

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Some research has been conducted in which the software itself records the actions of the learner. The difficulty with this method is that it is not possible when analysing the data afterwards to know, for example, whether a long pause between two learner actions may be due to the learner thinking about the task, talking to a fellow pupil, or being distracted to do something totally unrelated. It is therefore almost always necessary to have direct observations as well to clarify these ambiguities.

The usual limitation of this approach is that it is very time consuming and labour intensive.

8.5.4 Pupils' work

In addition to using standard tests and observations, some researchers have collected and analysed pupils' own work. This includes pupils' word-processed work, models of processes, multimedia presentations, Logo micro-worlds etc. These examples have been shown to provide evidence of pupils' attainment and/or changes in understanding. However, in analysing pupils' products it is necessary to link these closely to the ICT experiences and to know the processes through which the pupils have produced the work, such as drafting and redrafting a story. Account also needs to be taken of other educational inputs and experiences, including the intervention of the teacher, which may have contributed to the production process.

8.5.5 Pupils' and teachers' questionnaires and records

A frequently used way of finding out how pupils and teachers have used ICT is through detailed questionnaires or records of activities. The literature review shows that questionnaire surveys can provide evidence of teachers' and pupils' uses of ICT. However, even for those questionnaires which ask for details of specific uses of ICT, it is difficult to acquire reliable evidence of the *quality* of use. Therefore these methods provide useful baseline data which, when augmented with more detailed observational data, will provide an adequately comprehensive measure of the learning experience with ICT.

A common method for finding out how and when teachers use ICT is through questionnaire surveys. However, the first ImpacT study showed that this could be misleading, unless the data is confirmed through pupils' regular records of ICT uses in their lessons (Watson, 1993). Pupils' records of ICT use were collected once a term in the ImpaCT2 study (Harrison *et al*., 2002); this is not frequent enough to demonstrate reliably what the ICT uses in specific lessons were. Additionally, pupils may make the greatest use of ICT at home or in a subject not being studied. This ICT use can have an indirect effect on pupils' learning in the subject under study. Ideally, it would be worth collecting pupils' and teachers' records of ICT use in every lesson.

8.5.6 Other methods

A range of other research methods are reported in individual studies, which may also be of use to further research. So far in these conclusions the focus has been on pupils' tests, or ICT products and observations of pupils in lessons. Several studies reported on pupils' explanations being improved by the uses of ICT. Therefore it is also important to assess pupils' oral presentations as well as written ones.

Techniques which are more commonly used in other areas of educational research have also been found to produce reliable evidence of pupils' learning and understanding. These include the use of repertory grids to examine pupils' understanding of concepts of mechanics in science, using sheets of data to examine pupils' data-handling skills and using concept maps to measure pupils' understanding of ICT resources and devices. In using such resources it is important to know the relevant theories underlying such techniques. An example of where this might lead to insecure conclusions is the use of concept maps for pupils drawing links between ICT devices, as in the ImpaCT2 study. Concept maps are more commonly used in studying pupils' understanding in science, and are devised in several stages, which include a correlation and weighting of the various concepts. Research in this area has shown that when asking the subject to draw out a set of ideas and relationships, the resultant product can change each time the drawing is produced. Therefore it is difficult to separate out any conclusions about understanding of ICT which might be due to the learner's priorities on that particular day, or having experienced a use the day before, etc., compared with measuring changes in understanding of ICT built up over a long period. However concept maps do indicate the range of ICT uses which pupils know or think they know about.

Finally, 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 therefore analysed the text of

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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 presentations.

In conclusion, this literature review has confirmed that specific uses of ICT have had 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 ICT use. Researchers need to take account of ICT leading to new forms of knowledge and knowledge representations, and therefore new types of achievement.

8.6 Limitations of the literature review

Due to the limited time available to research and write this literature review, it was not possible to review all the literature which exists. As explained in the introduction, this review focused on literature most relevant to ICT and attainment. Publications that were not covered include specialist subject journals in some areas (humanities, art etc.) which would have papers on the use of ICT in education. There are also many other e-databases which could be searched, but this would take several person-years. There is also literature from other countries in, for example, French, German and Italian, which provides further evidence of ICT and attainment.

In spite of not being able to include all the above, what this literature review does show is that there is an immense amount of evidence about ICT and attainment already published.

8.7 Priorities for future research

This literature review provides evidence of the positive effects of different aspects of ICT on pupils' attainment. These positive effects are most prominent in science, mathematics and English, but the use of more appropriate measures and studies conducted over a longer time would have provided more robust evidence. It is also evident that it is not appropriate or possible to measure the effects of ICT on pupils' attainment without identifying what the actual use of ICT is. Therefore many more studies need to be done to confirm the findings presented here, and to extend the body of knowledge about the value of *specific* uses of ICT. The priorities identified here complement those listed in the pedagogical study (Cox and Webb, 2004), Section 7.10.

8.7.1 Long-term studies

Much research focuses on a specific impact of a specific use or intervention and during a particular period, such as the introduction of laptops into one school group. Although there have been long-term studies and meta-studies, more large-scale studies are needed for the following reasons:

1. To find out what effects specific uses of ICT, for example word processing in English and simulations in science, have on the learning of concepts and skills in specific topics and subjects.
2. To measure attainment which is sustained over a long period (at least two to three years).
3. To measure the effects of teachers' and pupils' ICT skills on the teaching and learning of specific subjects.
4. To monitor and assess the whole learning process, which is made up of a wealth of learning experiences for every school pupil.
5. To compare the effects of different uses of ICT on the learning of the same subject, eg learning science concepts using simulations and modelling, and using electronic whiteboards.
6. To measure the effects of ICT on the curriculum and consequently on the learning of the pupils.
7. To identify appropriate methods for measuring the effects of specific uses of ICT to take account of new ways of learning and new knowledge.

8.7.2 The effects of informal learning using ICT on attainment

There are a growing number of study centres with online access for learners, which will be contributing both to learners in otherwise formal education settings (5–16 years) and learners only in informal education. Research needs to be conducted to measure how these 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

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retention of new skills and knowledge. One approach would be to map individual pupils' learning experiences with and without the use of ICT over a substantial period.

8.7.3 Developing new methods of measuring attainment

The research has shown that some methods of measuring the effects of ICT are more effective and reliable than others. Further research needs to be conducted, which will involve a range of measures to assess the effects of different uses of ICT on pupils' attainment, together with the effects of other non-ICT based learning experiences, and the strengths and weaknesses of various measures (see Section 8.5 above).

8.7.4 Beyond the lesson

Many of the research studies reported here have focused on the learning experiences which happen in a particular series of lessons. However, previous research has shown that using ICT in a lesson has effects in other areas, as do many other learning experiences. For example, the building of computer-based models will affect the way in which pupils think about their reasoning in science. This will affect how they apply this reasoning in all science lessons and in other subject lessons. Using presentation software to present pupils' work has been shown to enhance their presentation skills, their ability to give more scientific explanations, and to communicate ideas. Therefore 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.

8.7.5 Literature review

This literature review has provided substantial evidence of the effects of ICT on attainment. However, a longer literature review, which would enable the researchers to categorise groups of studies in relation to the types of ICT uses more comprehensively, would provide more substantial evidence of specific uses of ICT and pupils' learning. For example, the review could be extended to include research studies into the effects of modelling with and without ICT on pupils' learning in science. There are many curriculum areas where the evidence is less extensive, eg art, music and religious education. A larger review would enable the researchers to study more of the US and Australian literature and foreign language literature (eg French and German research) which would enhance the evidence provided in this report.

There are many individual PhD theses which could not be accessed in the time available, which provide detailed well-researched evidence of ICT and attainment, and also describe innovative methods. These could also be included in a longer more extensive review of the field. The ICT environment is changing, and so are knowledge and the representations of knowledge. Therefore a review of the literature relating to psychology and artificial intelligence would provide a solid foundation for the work reported in this study.

Finally, this literature review describes a large range of research studies which show a varied but positive effect of ICT on pupils' attainment, but it also shows that positive outcomes are usually determined by the pedagogical reasoning and knowledge of the teacher. These effects are also influenced by the types of ICT uses, which are forever changing. Therefore further research in this area should be a very high priority in order to capture the best and most effective uses of ICT in education.

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Appendix 1

Keywords

ACCESS	INNOVATION INTEGRATED LEARNING
ACHIEVEMENT	SYSTEMS
ADULT EDUCATION	INTERNET
AGE	LEAGUE TABLES
ART	LEARNING PROCESSES
ASSESSMENT	LIFELONG LEARNING
ATTAINMENT	LITERACY
ATTITUDES	MATHEMATICS
BARRIERS	MOBILE TECHNOLOGIES
BEHAVIOUR	MODERN FOREIGN LANGUAGES
CALCULATORS	MOTIVATION
CD-ROM	MUSIC
CLASSICS	ON-LINE LEARNING
CLASSROOM PRACTICE	PEDAGOGIES
COGNITION	PHYSICAL EDUCATION
COMMUNICATION	PRIMARY
CONFIDENCE	PROBLEM SOLVING
CPD	PUPIL : COMPUTER RATIO
CREATIVITY	RELIGIOUS EDUCATION
DIFFERENTIATION	SCHOOL SETTINGS
DISTANCE LEARNING	SCIENCE
E-LEARNING	SECONDARY
ENGLISH	SKILLS
EPISTEMOLOGIES	SOCIAL CHARACTERISTICS
GEOGRAPHY	SPECIAL EDUCATIONAL NEEDS
HISTORY	TEACHING INTERVENTIONS
ICT	TEACHING METHODS
ICT ENVIRONMENTS	TEACHER EDUCATION
INCLUSION	WHOLE CLASS TEACHING
INDIVIDUALISED LEARNING	
INFORMAL LEARNING	

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Appendix 2

List of journals identified

ACM Transactions
American Educational Research Journal
Applied Linguistics
Assessment in Education
Association for Learning Technology Journal
Association for Science Education Bulletin
Australian Journal of Educational Technology
Biochemistry and Molecular Biology Education
British Education Index
British Educational Research Journal
British Journal of Educational Studies
British Journal of Educational Technology
British Journal of In-Service Education
British Journal of Sociology of Education
British Journal of Special Education
British Journal of Teacher Education
Changing English
CITE
Cognitive Psychology
Comparative Education
Computer
Computer Assisted Language Learning
Computer Education
Computer Networks for Research in Europe
Computer Physics Communications
Computer Supported Co-Operative Work
Computers and Composition
Computers and Education
Computers and the Humanities
Computers in the Schools
Curriculum Journal
DES Report on Education
Education
Education and Computing
Education and Information Technologies
Education and Training
Education for Primary Care
Education for Teaching
Education in Chemistry
Education in Science
Education Index
Education Review
Education Today
Educational Communication and Technology
Educational Computing and Technology
Educational Media International
Educational Research
Educational Studies in Mathematics
Educational Technology Abstracts
Educational Technology Research and Development
Educational Technology Review
English for Specific Purposes
English in Education
English Today

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European Journal for the Learning of Mathematics
European Journal of Education
European Journal of Science Education
European Journal of Special Needs Education
Gender and Education
General Education
Higher Education
Higher Education Review
Holdings
Human Computer Interaction
IEEE Transactions on Education
Independent Learning in Science Newsletter
Individualising Learning in Science
Information Technology in Teacher Education
Information, Communication and Society
Innovations in Teaching and Learning in Information and Computer Sciences
Instructional Science
International Education Review
International Journal of Computer Vision
International Journal of Educational Development
International Journal of Educational Research
International Journal of Mathematical Education in Science and Technology
International Journal of Science Education
International Review of Education
International Yearbook of Education
Internet and Higher Education
Issues in Education
Journal for Research in Mathematics Education
Journal of Biological Education
Journal of Chemical Education
Journal of Computer Assisted Learning
Journal of Computers in Mathematics and Science Teaching
Journal of Curriculum Studies
Journal of Education
Journal of Education for Teaching: International Research and Pedagogy
Journal of Education Policy
Journal of Educational Computing Research
Journal of Educational Resources in Computing
Journal of English for Academic Purposes
Journal of Environmental Education
Journal of General Education
Journal of Higher Education
Journal of Information Technology for Teacher Education
Journal of Mathematical Behaviour
Journal of Research on Computing in Education
Journal of Research on Technology in Education
Journal of Science and Mathematics Education in Southeast Asia
Journal of Science and Technology
Journal of Second Language Writing
Journal of Social Policy
Journal of Special Education
Journal of Teacher Education
Journal of the Philosophy of Education
Language and Education
Language Learning and Technology
Language Teaching
Language Teaching Research
Learning and Individual Differences
Learning and Instruction

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Learning and Motivation
Linguistics and Education
Mathematical Education for Teaching
Mathematics in School
Mathematics Teacher
Mathematics Teaching
Media Education
Media in Education and Development
Multimedia Information and Technology
NCTM News Bulletin
New Research in Education
Pedagogy
Physics Education
Programmed Learning and Educational Technology
Psychology Learning & Teaching
Psychology of Learning and Motivation
Quarterly Journal of Education
Research in Education
Research in Post-Compulsory Education
Research in Science and Technological Education
Research in Science Education
Research Papers in Education
Research Strategies
Resources in Education
Review of Educational Research
Review of Research in Education
Scandinavian Journal of Educational Research
School Effectiveness and School Improvement
School Leadership and Management
School Science and Mathematics
School Technology
School Technology Bulletin
Science and Education
Science and Technology Abstracts
Science Education
Science Education News
Science Education Newsletter
Sixth Form Mathematics Bulletin
Social Policy and Administration
Social Science Journal
Social Science Research
Social Studies of Science
Sociology of Education Abstracts
Sociology of Education
Studies in Educational Evaluation
Studies in Linguistics and Language Learning
Studies in Science Education
Teacher Education
Teaching and Teacher Education
Teaching Children Mathematics
Teaching Mathematics and its Applications
Technology in Society
Technology, Pedagogy and Education
The World of Learning
Times Educational Supplement
Trends in Education
West African Journal of Education
Westminster Studies in Education
World Yearbook of Education

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Written Language and Literacy
Year Book of Education
Zentralblatt Fur Didaktik Der Mathematik (International Reviews on Mathematical Education)

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Appendix 3

Prioritised list of journals for searching

ACM Transactions
American Educational Research Journal
Applied Linguistics
British Educational Research Journal
British Journal of Special Education
Changing English
CITE
Computer Assisted Language Learning
Computers and Education
Education and Information Technologies
Education in Chemistry
Education in Science
Educational Studies in Mathematics
English in Education
European Journal for the Learning of Mathematics
European Journal of Education
International Journal of Mathematical Education in Science and Technology
International Journal of Science Education
International Review of Education
Journal of Biological Education
Journal of Chemical Education
Journal of Computer Assisted learning
Journal of Education policy
Journal of Educational Computing Research
Journal of Information Technology for Teacher Education
Journal of Science and Mathematics Education in Southeast Asia
Research in Science and Technological Education
Research in Science Education
Review of Educational Research
Science and Education
Science Education
Science Education News
Science Education Newsletter
Studies in Science Education

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Appendix 4

Methods of collating and categorising the literature evidence

The mechanism established for reviewing, collating and cataloguing items was based on the relevant fields provided in Endnote. These were:

- Author.
- Year.
- Publication name, eg name of journal.
- Volume (where relevant).
- Issue (where relevant).
- Abstract.
- Notes.

Where an academic paper included an abstract, this was recorded in Endnote and extended to provide sufficient analysis and review of the paper in question. The notes written by the specific reviewer were aimed at providing conclusive comment about the context, value, reliability and importance of the evidence or theory in the document being reviewed.

The areas and types of studies for review included the following:

- 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, eg age, gender, class, ethnicity.
- Evidence relating to factors which might influence the learning outcomes, such as teachers' pedagogies, ICT environment, level of ICT resources, and so on.

The review also includes important categories of evidence and theories of ICT in education (see Appendices 1 and 2) including *but not confined to* statistical evidence, where provided, of:

- the effects of ICT on attainment
- the frequency and range of use of ICT in schools and the home
- differential access and use in relation to social characteristics
- the changing nature of provision of ICT-related education resources
- qualitative studies and case studies of the use of ICT in different school settings and subjects
- the ways in which use of ICT relates to the ICT resource and learners' attainment
- the different aspects of learning promoted by ICT use
- the use of ICT in informal settings
- attitudes of pupils towards ICT-linked innovation.

Theories developed in the literature were also used to inform the analysis. These included:

- theories of innovation and change
- theories of behaviour and attitudes towards ICT
- theories of the application of ICT to education.

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