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FACULTY OF SOCIAL SCIENCES

School of Education

Teachers' Views on the Impact of ICT on the Teaching and Learning of Secondary Mathematics: a Multi-modal Study

By

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Dissertation for partial fulfilment for the degree of Master of Philosophy (Research Methods)

March 2004

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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TEACHERS' VIEWS ON THE IMPACT OF ICT ON THE TEACHING AND LEARNING OF SECONDARY MATHEMATICS: A MULTI-MODAL STUDY

by Rosalyn Margaret Hyde

There continues to be much debate about the impact of ICT in teaching and learning in mathematics. Collectively, large-scale studies of the impact of technology on attainment using measures such as national examination scores do not show a clear positive link between the use of technology and attainment in mathematics. However, there is much evidence within secondary mathematics education research that suggests that the use of technology is beneficial to the teaching and learning of mathematics.

The study here reports the findings of a small, local multi-modal study. Teachers were asked to respond to a questionnaire giving scores for a list of software and hardware for the frequency of use and impact on pupils' learning in secondary mathematics. They were also asked to give an indication of the use they put these items to, and an overall score for both Key Stages as to the impact ICT had in mathematics in their school. Two teachers were also chosen as short case-studies and were observed teaching with ICT and then interviewed about their practice.

The findings indicate that many teachers were positive and enthusiastic about the use of ICT in teaching and learning mathematics and that the level of impact was largely similar between the two key stages under investigation. The availability of resources differed substantially, with some mathematics departments being well equipped and others finding access to resources very limited. Teachers reported using the resources they had with different levels of frequency and with different considerations as to the impact those resources had on pupils' learning. The picture overall is one where departments and teachers are in a very experimental phase, where they are exploring these uses of ICT and starting to find that this has implications for both pedagogy and practice.

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Acknowledgements

I would like to thank those teachers who took part in the fieldwork for this study. Thank you too, to those colleagues who helped and supported me, particularly to Keith Jones, my supervisor. Particular thanks go to my husband, Shaun, for all his support and encouragement.

1. Introduction

1.1 Context

Computers have been used by pupils in schools for more than twenty years, yet there is continuing debate about their uses and benefits for teaching and learning. In part this is because the technology changes very rapidly so applications that a few years ago might have seemed impossible have become more commonplace.

In recent years there has been huge investment in the U.K. in hardware, connectivity and software in schools and a large increase in home computer and Internet use. This is demonstrated by Ofsted (2002b), which reports the total expenditure over all ICT related initiatives in schools over the period 1998 – 2004 as being £1.8 billion. The increase in home computer and Internet use is reported, Oftel (2003), indicates that 61% of UK homes have a PC and 50% of homes have Internet access (18% of these use broadband). This compares with figures for January 1999 when approximately 40% of homes had a PC and only 12% had Internet access (Oftel, 2000). Figures from BECTa (2002b) suggest that access to ICT resources at home is greater for school-age children than is demonstrated in the population as a whole. 90% of pupils taking part in the ImpaCT2 study reported having a computer at home and 73% reported having the Internet at home (BECTa, 2002b). It should be noted that these figures are averaged out across key stages 2 to 4 and the study also found that access to ICT resources at home increased with age, suggesting that figures for pupils in Key Stage 4 are higher than these.

Large scale investment, new technologies and the rapid pace of change characterise the current climate and it is within this climate that questions are being asked in different forums about the effectiveness of Information Communications Technology (ICT) in schools.

Within secondary mathematics education there are well-established and well-researched uses of ICT in teaching and learning, as well as a huge variety of new resources available that utilise a wide range of technology. Mathematics departments in schools have differing resources for integrating ICT into their teaching and also use these resources in differing ways.

1.1.1 School reform and government priorities

The use of ICT in schools is high on the U.K. Government's agenda for school reform. The Department for Education and Skills (DfES) believes that ICT has a 'massive contribution' to make to school reform, that it can make a 'significant contribution' to teaching and learning, provide opportunities to engage and motivate and enable schools to share good practice (DfES, 2003, p.2&3). Programmes, projects and resources such as Curriculum Online (www.curriculumonline.gov.uk), Laptops for Teachers (lft.ngfl.gov.uk), Online CPD (various providers), ICT TestBed Project (www.dfes.gov.uk/icttestbed), Teachernet (www.teachernet.gov.uk), Classroom of the Future (www.teachernet.gov.uk/classroom_of_the_future), and others, demonstrate government commitment to these aims.

1.1.2 Investment

As a component of overall U.K. investment in ICT provision in schools, the British Educational Suppliers Association (BESA, 2003) reports 1.23 million desk top computers and 180 000 laptop computers in schools with a forecast of the total number of computers in schools growing to at least 1.6 million by April 2003. They also report that £426 million was spent by UK state schools on ICT products and services in 2002 and that expected expenditure in these areas is a total of £493 million for 2003. There has also been significant expenditure on training for teachers with £230 million of Lottery funds spent on New Opportunities Fund training to increase the competence of teachers in using ICT in teaching and learning (Ofsted, 2002b). The DfES (2003, p.7) have announced their intention to commit further expenditure to 'a comprehensive range of professional advice, guidance and professional development to embed ICT in subject teaching'.

1.1.3 Practice in schools

Despite this level of investment and support from government, the picture in terms of teaching and learning in secondary mathematics is yet to reflect the expected corresponding wide use of ICT. The Ofsted report on mathematics in secondary schools published in 2002 (reporting data from 2001) says that:

> The use of information and communication technology (ICT) to promote progress in mathematics remains a relatively weak aspect of provision. It is unsatisfactory in one school in three and is good or better in a quarter of schools. (Ofsted, 2002, p.3)

The report details both a lack of consistency in practice within departments and that pupils' access to software varies greatly. It goes on to say that: '...only a small proportion of departments has (*sic*) reached the point where they can evaluate critically their use of ICT and decide where it most benefits learning in mathematics.' (p.9)

Similar outcomes are found, again by Ofsted, in the evaluation of the second year of the Key Stage Three Strategy (Ofsted, 2003). They report that few schools made use of ICT to enhance the teaching of mathematics and that, even in schools where there was sufficient access to computers, the use of ICT was inconsistent because some staff lacked confidence in using it.

1.2 Research Focus

The previous section outlines the contexts within which this research was undertaken. The work described here is a small-scale local study into the impact of ICT on the teaching and learning of secondary mathematics within a defined set of boundaries. It seeks to extend, deepen and add to the current knowledge base in this area.

Key questions relate to surveying current practice and seeking to investigate the impact this practice has on the teaching and learning of mathematics. So, as a very first step, a teacher from each school in the target area was asked to:

- Identify what software and hardware they use;
- How frequently they use it;
- What impact they think it is having on teaching and learning; and to
- Give an indication of what they are using it for.

This will allow the building up of a 'snapshot of practice' as reported by teachers across a defined sample of schools, which can then be compared with existing national data in this area. It also allows for some exploration of a possible relationship between the frequency of use of a resource and its impact on teaching and learning.

Additional data from the surveys and from some school visits enables further analysis of these questions seeking to examine teachers' practice with ICT within secondary mathematics education and the impact teachers believe this has on pupils' learning of mathematics.

These lines of enquiry raise some complex sub-questions. What is being surveyed in this study is what teachers report themselves as doing, so one issue here might be about the relationship between teachers' perceptions and practice. Another issue to consider is the extent to which teachers are able to describe what the use of ICT adds to their teaching and how it impacts on learning. These issues are explored through the data from school visits that form part of this study.

One of the bigger questions underlying this study is some consideration of whether time and effort are being invested in those things that have the most positive benefits on teaching and learning. Another is to find out the extent to which teachers modify their pedagogy to incorporate new tools. A further question is to determine the implications for both Continuing Professional Development and Initial Teacher Education.

2. Use of computers in school mathematics and its impact on teaching

2.1 Introduction

Researchers acknowledge that, although many research projects have found the use of technology to have a substantial impact on the teaching and learning of mathematics, the use of technology has yet to become commonplace in schools and colleges. Ruthven & Hennessy (2002, p.48) report that computer use remains low and growth slow and Balacheff & Kaput (1996, pp.469) suggest that the impact of technology on teachers' daily practice has yet to match expectations. Mariotti, (2002, p.696) detects a 'certain hostility' in schools towards technology and that whilst the equipping of schools with technology has been slow, the integration of this technology into school practice has been even slower (p.720). A similar point is made in Hedges et al (2003, p.2) where the authors note that '...even though teachers have had increasing access to computers.... very few actually use them'. Mariotti (2002, p.697) also notes that the presence of computers does not always produce what is expected.

Part of the reason for this low level of use and slow uptake is that the education system resists change (Hedges, 2003, p.3), so new technology is only used in ways that support current practice. Other researchers comment on this factor as well. Stoddart and Neiderhauser (1993, p.17) quote Cohen and Cuban as describing this by saying that new technology will be 'bent' to fit existing practice. Hedges et al (2003, p3) describe new technology as being used in 'old' ways and Balacheff & Kaput (1996, p.470) use the phrase 'historic inertia' for this phenomenon. All three of these sets of authors provide us with graphic images to illustrate the situation in schools.

It is this situation that this chapter sets out to review. The factors considered here relate to teacher-training and the pedagogical ways in which teachers use technology. These matters are discussed in more detail below. In this context it should also be noted that technology does not necessarily serve as time-saving for teachers, but in fact makes significant demands on teachers in terms of time and effort (Stoddart & Niederhauser, 1993, p.17).

2.2 Effect of using ICT on attainment in secondary mathematics

There have been a number of large-scale studies, both in the U.K. and elsewhere in the world, investigating the impact of the use of ICT on attainment in standardised or national tests. This section summarises and comments on three recent studies from the British Education and Communications Technology Agency (BECTa), sponsored by the DfES. It also examines a report from the Education Testing Service's Policy Information Centre in the U.S.A. (Wenglinsky, 1998), which uses data from a large national American survey and from a recent large-scale study in Israel. The particular focus here is on what these studies report about the impact of ICT on attainment in mathematics.

2.2.1 ImpaCT2

ImpaCT2 is a large-scale project using a range of data collection methods from a large sample of schools investigating a number of aspects relating to the use of ICT in schools.

The particular report under discussion here (BECTa, 2002a) looks at the relationship between the effective implementation of ICT and performance in National Tests at Key Stages 2 and 3, and GCSEs at Key Stage 4, using a sample of 55 schools. In each school, data on initial achievement, ICT experience and final attainment was collected for a sample of pupils. Data on ICT experience were collected by questionnaire, with pupils allocated to either the 'High ICT' group or the 'Low ICT' group, based on their level of use of ICT in a particular subject. The scores reported by pupils for subject areas were used to calculate a mean subject-related score. These mean subject-related scores were used to allocate schools to High, Intermediate or Low ICT provision groups. Relative gain scores were calculated for pupils comparing their predicted scores with their actual scores in the final attainment tests for their age group.

Positive associations were found for mathematics at Key Stage 2, but they were not as statistically significant as the results for English. The study estimates that high ICT use in mathematics can help to raise performance in mathematics by 1.69 marks or 0.061 of a National Curriculum level. This is equivalent to an acceleration of 6.1% of two years' achievement in Key Stage 2 mathematics. 47% of pupils reported using ICT at least some weeks in mathematics lessons (p.2).

At Key Stage 3 there were no clear-cut associations other than for science. High ICT use raised mathematics performance by 0.083 of a NC level and accelerated progress through the levels by 8.3% of two years' achievement. 33% of pupils reported using ICT at least some weeks in mathematics lessons. At Key Stage 4, 18% of pupils reported using ICT in mathematics lessons at least some weeks (p.2-3). The difference in relative gains for pupils' performance between High and Low ICT use were not statistically significant for mathematics at Key Stage 4 (p.31).

Clearly, these results only show small positive effects on pupil attainment. There are a number of possible explanations for this. As the research team note, the proportion of lessons using ICT was generally low (p.3) and this leads to less data being available on which to make comparisons, which in turn affects the statistical significance of any findings (p.6). They also report that some of the reported ICT use was skills-based rather than curriculum focused (p.32). It must also be noted that no ICT use is allowed in the National Tests used at Key Stages 2 and 3, nor in the GCSE at Key Stage 4 and, furthermore, calculator use is banned in some papers. The curriculum in England is heavily assessment-driven, so the effects of these kinds of examinations on teacher behaviour might be to discourage or marginalise the use of ICT. This point is supported in the report:

> '...the overwhelming response was that, adding to the disappointing picture of little use lower down the school, preparations for GCSE often constrained the use of ICT for teaching and learning in mathematics'. (p.36)

Comparison of mathematics with other subjects bears comment at this point. While fewer Key Stage 4 pupils report never using ICT in mathematics (27%) compared to English (32%), the general level of use of ICT in mathematics is lower than in English. Nearly 70% of Key Stage 4 pupils report never or hardly ever using ICT to support their learning of mathematics in school outside mathematics lessons. It is also noted (p.3) that there is no consistent relationship between the average amount of ICT use reported for any subject at any Key Stage and any raising of achievement.

Given the low levels of ICT use being reported by pupils, it is hard to see how this research would have been able to produce any findings that would have shown a positive impact for ICT on attainment in mathematics.

2.2.2 The Secondary School of the Future

The picture painted by this report is more positive about the impact of ICT on attainment than the BECTa report, although it should be noted all the data was from secondary sources which may have an effect on the findings.

The report (BECTa, 2001) was commissioned by the DfES to investigate the relationship between ICT and educational standards. It uses data from Ofsted, the Qualifications and Curriculum Authority (QCA) and the DfES. The data analysis seeks to establish direct causal links, for example if ICT is having an impact on attainment, then good ICT teaching should also have a link with attainment. Schools are compared with others of similar socio-economic background and with those of similar pupil attainment in order to try and isolate the effect of ICT.

Secondary schools with 'Very Good' ICT resources[1] achieved, on average, better results on the 1999 Key Stage 3 tests in mathematics than those with 'Poor' ICT resources. At Key Stage 4 achievement was higher for pupils in those schools with 'Very Good' ICT resources but there is no data available for individual subjects. Schools that used ICT to support mathematics generally had better achievement in mathematics than schools that did not. Similar results linking a good level of ICT resources to higher attainment were obtained when schools were compared with those having similar socio-economic factors and when compared with schools having the same levels of pupil prior attainment. (p.7)

The report suggests that there may be a threshold level of ICT resourcing needed for effective use of ICT in supporting curriculum achievement. Attainment in mathematics was highest in schools that used ICT to support mathematics and in at least four other subjects (p.7). However, where ICT use was restricted to one subject, there as little evidence of impact on attainment. This suggests that pupils are able to develop ICT skills that are transferable between subjects and that they can use these both to support higher order thinking in curriculum areas and to support independent learning (p.8).

[1] This was determined by Ofsted inspectors who assessed the 'adequacy of resources' to meet the demands of the ICT curriculum. The judgement is for the school as a whole.

Important factors in raising achievement through the use of ICT are identified as:

- Whole school support for ICT across the curriculum;
- Use of ICT across the curriculum;
- Good quality teaching of ICT;
- Good ethos for learning in ICT;
- Positive attitude by pupils to ICT;
- Good use of ICT resources (p.8).

Data about the level of ICT resources in schools came from judgements made by Ofsted inspectors in recent inspections according to the 'adequacy of resources' to meet the demands of the ICT curriculum (p.10). This data reflects whole school provision of ICT and therefore does not explore differences in resourcing and provision between subject areas, nor any difference in the experiences of individual pupils (p.7). One might perhaps have some reservations about this data in that it was not collected for the purpose for which is has been used. It also does not shine any light on the deployment of resources in school, particularly in subject areas, which must be a critical factor determining the impact of ICT on teaching and learning in subjects.

The section in the report that looks at the relationship between attainment and ICT use in subjects draws on data from a DfES survey of ICT in schools. Headteachers in 50% of the schools taking part in the survey reported that ICT was used substantially to support mathematics (p.22). Given the low proportion of schools assessed by Ofsted as having even satisfactory ICT resources reported in this study, one wonders how so many schools can be making such good use of ICT in a subject area (particularly given that similar proportions claimed substantial use of ICT in English and science). No reference is given to the survey results or about the sampling technique used for this data set.

As in the ImpaCT2 study, one of the problems in claiming validity for the results obtained was that relatively few schools reported high levels of ICT use. Thus, in this study, only a small proportion of the schools in the sample were assessed by Ofsted as having 'Very good' or 'Good' ICT resources. Calculating an accurate percentage for the schools in each of the categories ('Very good', 'good' etc.) is not possible because the total number of schools reported in the survey (409) is less than the total for all the categories together (446). However, something like only 11% of schools were reported as having 'Very good' ICT resources and about 46% as having unsatisfactory ICT resources.

2.2.3 Secondary Schools: ICT and Standards

A very recent report (BECTa, 2003b) uses the same sources of data as BECTa (2001) but from a later date. 'Secondary Schools of the Future' (BECTa, 2001) uses data from the school year 1998-9 and 'Secondary schools: ICT and Standards' (BECTa, 2003a) uses data from 2000-1. The conclusions from this later report are far more positive than the earlier one about the effect of ICT on schools standards and their leading remark is:

> There is a clear and positive relationship between good ICT learning opportunities and higher pupil achievement in secondary education (BECTa, 2003b, p.8)

More specifically, the report states that better ICT learning opportunities lead to higher achievement in mathematics at Key Stage 3 and GCSE. It also finds that good use of ICT in mathematics is an indicator of good teaching in mathematics, although there were departments where mathematics teaching was good but ICT was not used well (BECTa, 2003b, p.34).

The report is clear that it finds a more positive link between use of ICT and raising attainment than earlier similar studies. However, as one of the appendices says '...there are obvious limitations with the use of school level inspection data' (p.56). Data for this study was not originally collected for the express purpose of determining the impact of ICT and we cannot be sure that the interpretations match with Ofsted's intentions when they first collected it. What is of concern though about these results is that, although there may be positive correlation between the two, there is not necessarily causality. It may well be that there are several intermediate links between good ICT learning opportunities and higher examination results. For example, something about the good ICT learning opportunities needs to cause the higher examination results, otherwise it could be concluded that it is due to schools with better ICT learning opportunities having pupils from a higher socio-economic background or the schools having more money. If we assume that there is a direct link between ICT learning opportunities and higher attainment then unfortunately, this report does not tell us how the two interact and what cognitive processes are at work, for example.

2.2.4 Educational Technology and Student Achievement in Mathematics

Wenglinsky's (1998) report is of a large-scale national study in the U.S.A. using data from the 1996 National Assessment of Educational Progress (NAEP). The data analysed by Wenglinsky from NAEP is that referring to amount of computer use, teachers' professional development, types of computer use, pupil achievement in standardised tests, and measures of the social environment of schools for fourth and eighth-grade students. Wenglinsky says that 'In essence, the study found that technology could matter, but that this depended upon how it was used' (p.3). He concludes his report by saying that '...when they are properly used, computers may serve as important tools for improving student proficiency in mathematics as well as the overall learning environment in the school.' (p. 4)

Wenglinsky is clear about some of the shortcomings of his study. He notes that it does not distinguish between the effectiveness of different types of software, and this seems to me to particularly important given his findings. His categorisations depended on those used in the original NAEP survey and these did not allow him any finer detail for analysis. He also notes that he was not able to make allowance for states having different technology policies, that the study does not contain any measures of prior achievement and that the data on teacher practices was very general (again a result of the survey data) (p.33).

However, what is more significant in analysing Wenglisky's findings is the report from the U.S. National Centre for Education Statistics (Hedges et al, 2003). The report examines the three questions in the survey about computer use and concludes that the data is neither valid nor reliable in that the questions were ambiguous and the results do not correlate with one another. The authors also produce compelling arguments that the data from the NAEP survey is simply unsuitable for the kind of analysis Wenglinsky carried out because of its cross-sectional nature and its weakness in measuring key background factors. They state that:

> ...given the weaknesses of NAEP data for causal inference, even tentative conclusions about the relation of achievement and computer use on the basis of the NAEP data are not warranted. (p.38)

Hedges et al (2003) make specific mention of Wenglisky's findings. Their major concern goes as follows: computer use and achievement are also related to race and ethnicity so this could have led to the apparent negative relationship between computer use and achievement (p.3). They also claim that Wenglisky did not make use of the best available data in NAEP on socio-economic status and that he did not look at teacher-reported computer use, as opposed to pupil-reported use, which might be a more valid indicator of teaching method.

In summary Hedges et al conclude that the NAEP data is not suitable in general for the investigation of causal relationships, for looking at the effect of technology on attainment in particular, and that there are some problems with some of the data Wenglinsky selected for analysis. They recommend changes to the NAEP survey questions and alternative research design methods to investigate the relation between use of computers and attainment. It should also be borne in mind that the NAEP data is designed for the purpose of measuring the achievement of students as a whole.

2.2.5 Tomorrow-98

Angrist & Lavy's (2001) study of the large-scale introduction of computers into elementary and middle schools in Israel says that the results of their study '...do not support the view that CAI improves learning, at least as measured by pupil test scores' (p.20). The study also finds a negative and marginally significant relationship between the use of computers and 4th grade mathematics scores (p.20). The final sentence of their paper is damning: 'On balance, it seems, money spent on CAI in Israel would have been better spent on other inputs' (p.22).

There are a number of questions to raise about these research results. Angrist & Lavy do not necessarily seem to have approached this study entirely without bias, given comments such as '...there are good reasons to believe that computers can actually be a diversion' (p.2) and '...our sceptical view of the value of expenditure on education technology is reinforced by our earlier findings' (p.22).

Of greater concern is the lack of data reported by them on how teachers used the computers placed in schools. This is a particular concern given Wenglinksy's (1998) finding that the mode of use is important in determining the impact of technology on learning. This lack of data is also concern given the body of research suggesting that teachers, and schools, tend to assimilate new technologies into existing pedagogies.

In her critique of Angrist & Lavy's work, Lynch (2002) notes this point. She goes on to say (p.3) that Angrist & Lavy only distinguish between Computer Aided Instruction (CAI) and Computer Skills Training and these form only a crude categorisation for computer use in schools. The use of the term CAI throughout the paper seems to me to be out of place, as this is generally now a dated term replaced in recent literature with a range for more explicit and descriptive terms for the use of technologies in the classroom. The study also gives no indication of the software used on these computers and the models and range of classroom use employed by teachers.

Angrist & Lavy report that (p.20) '...no evidence of significant change in educational inputs, instructional methods, or teacher training'. Lynch (2002, p.4) sums up the approach by teachers in the project to computers as '...computers were used in routine ways to support learning'. This is of concern, as in my opinion, a project on this scale (35 000 computers were installed in 905 schools) should have led to some changes in classroom practice. Claims are made by Angrist & Lavy that use of computers in teaching does not improve pupil test scores but this is not surprising given that the computer use examined is not innovative, nor different in any significant in any way from the preceding non-computer classroom practice.

2.2.6 Summary

For a variety of reasons, the large-scale studies considered here do not necessarily show a clear positive impact of the use of technology on measures of attainment such as national examination results in mathematics. We have some evidence from one study linking the use of ICT in schools and attainment as measured by standardised tests. However, we are yet to have clear and unambiguous evidence of such a relationship from a wider range of studies, and without the concerns raised about the study in question (BECTa, 2003b).

2.3 Tools and technologies used in secondary mathematics education

One of the issues raised by the studies reviewed above is that it is not necessarily the presence of computers that means that there is a positive impact in pupils' mathematical achievement, it is how those computers are used. The English study detailed below seeks to explore this in more detail.

The Fischer Family Trust (www.fischertrust.org) is a non-profit organisation that carries out education development projects in the UK. One of their projects, sponsored by Research Machines plc (a large supplier of software and hardware to schools), is a study into 'High Impact ICT Resources' (Fischer Trust, 2002) in primary and secondary schools. The data for secondary mathematics collected in 2000 and again in 2001 consists of 1312 resource ratings provided by 314 mathematics departments. The questionnaire was mailed to all schools in the UK and was also available on the Internet. Respondents were invited to list those ICT resources (software, web sites, specialist peripherals, communications and hardware for whole-class teaching) they used and indicate the frequency of use and the impact on pupils' learning in mathematics.

The table below lists the top ten resources in order of impact rating:

Item	Impact rating
Interactive whiteboard	3.6
Autograph (graphing and statistics) http://www.autograph-math.com/	2.9
Successmaker (ILS) http://www.rm.com	2.9
Graphical calculators	2.8
Omnigraph (graph plotting) http://www.spasoft.co.uk/	2.7
BBC Bytesize website http://www.bbc.co.uk/schools/11_16/	2.7
Microsoft Excel	2.3
Coypu (graph plotting)	2.3
The Geometer's Sketchpad	2.3
Cabri Geometre II	2.3

Table 1: Resources listed in order of impact rating (top ten only)

The survey report states that an impact rating of 2.5 or more indicates that around 60% of responses rated this resource as having a significant or substantial impact on pupils' learning in mathematics. Table 1 lists a wide range of resources including whole-class presentation technology, an Integrated Learning System (ILS), small portable hardware, a web site, generic software and mathematical tools.

An interesting alternative analysis is given by sorting the full list according to number of responses, which gives an indication as to how many departments are using each resource, as shown in the table below:

Item	Number of responses
Microsoft Excel	185
Logo	124
Omnigraph	91
SMILE Mathematics (small software) http://www.smilemathematics.co.uk	91
Microsoft Word	56
Successmaker	54
Graphical calculators	40
NRICH website http://www.nrich.maths.org.uk/	36
Test for Success Maths	32
Cabri Geometre II	21
The Geometer's Sketchpad	21

Table 2: Resources listed in order of number of responses (top eleven only)

Table 2 shows that the top four items were used by a large number of the schools but that the number of responses then tails off very quickly. Two of the items featured in the table, including the most commonly used, are generic pieces of Microsoft software commonly 'bundled' in with hardware purchases. Another, Logo, has a version that is available free of charge. It should also be noted that Dynamic Geometry Software (Cabri Geometre II and the Geometer's Sketchpad) are used by only a few departments.

The next table shows those resources where frequency of use was considered to be 'high':

Item	Frequency of use
Email	High
Graphical calculators	High
Headstart http://www.headstartsoftware.co.uk/	High
Interactive whiteboard	High
Microsoft Excel	High
Microsoft Works	High
SMILE Mathematics	High
Successmaker	High
Test for Success Maths	High

Table 3: Resources listed as 'high use'

Those resources listed as 'high use' are those that teachers said they used regularly throughout the year (see table 3). Comparing the tables allows us to identify those resources that are 'high use' and 'low impact'. The four in this category are Email, Headstart, SMILE mathematics and Test for Success Maths. Email doesn't fit in this list given that is essentially a communications tool and the others are software specific to mathematics. This may be an indication of the perceived utility and necessity of email and that perhaps many mathematics departments had not made creative use of it. SMILE mathematics is also perhaps a surprising member of the list as it is well-established and generally well-regarded software.

Those items identified as 'high impact' but not 'high use' are of particular interest. These are Autograph, Omnigraph and the BBC Bytesize website. Coypu, The Geometer's Sketchpad and Cabri Geometre II follow closely behind with fractionally lower impact ratings. Other than the website mentioned, these are all pieces of software written specifically for mathematics teaching and cover similar mathematical topics. Lower frequency of use and 'high impact' might either suggest that these items are only of use for limited areas of curriculum or it might suggest that teachers are making considered decisions to use these pieces of software for specific topics. The former may be true of Coypu, which is specifically a graph plotter (and now no longer available), but the other four would be useful for a range of topics in mathematics.

This survey is the only research reporting the details of what mathematics departments are actually using. Caution should be exercised when drawing more general conclusions about the use of ICT from this data for three reasons. First, because it is a self-selecting sample, secondly because it would be dangerous to draw conclusions from this data about the proportions nationally using particular items and thirdly because, in such a rapidly changing climate, these figures cannot be considered necessarily to reflect current usage patterns.

2.4 Impact of ICT on secondary mathematics education

Despite the lack of hard evidence about the impact of ICT on attainment in mathematics as measured by standardised tests, there is a substantial body of research documenting the impact of ICT on pupils' learning in mathematics as measured in other ways.

Van Weert (1998, p.12) lists four areas where technology impacts on the mathematics curriculum:

- Numerical calculations;
- Computer Algebra Systems (CAS);
- Dynamic mathematical tools;
- Modelling of mathematical processes in programming.

Balacheff & Kaput (1996, p.493) believe that technology changes the nature of the subject matter and how it is used to understand the world. They also say that the use of technology in mathematics teaching challenges our preconceptions about what should be taught to whom and when (p.493-4).

More specifically, technology enables a change in the types of problems and examples used in mathematics teaching. It allows for more use of realistic problems, for example in the use of CAS, (Balacheff & Kaput, p.474) and it shifts statistics from computation to having a focus on choice, combination and analysis of methods (p.478). In terms of geometry they say that (p.477) dynamic geometry software makes some classical problems obsolete and that makes it possible for students to explore other problems not possible with physical geometrical instruments.

More fundamentally, there is a shift in the types of problems, the resources and hence the methods of solution available in the classroom (Mariotti, 2002, p.697). Balacheff & Kaput (1996, p.474) describe this as a shift from the deductive and algebraic to the inductive and empirical.

2.5 Key factors affecting the use of technology in schools

The literature documents a wide range of factors inhibiting the use of technology in schools. The inherent resistance to change in the school system has been mentioned previously and summed up by Cuban (2001, p.153) when he says:

> Technological changes takes far longer to implement in formal education than in businesses because schools are citizen-controlled and nonprofit. As systems they are multipurpose, many-layered, labour-intensive, relationship-dependent, and profoundly conservative.

Some of these are practical, some are technical, some are attitudinal and others are pedagogical. This discussion is made particularly complex because there are factors that are related to technical competency with ICT and other issues that are about pedagogy and these two interact.

2.5.1 Practical factors

The most commonly mentioned practical limitation affecting the use of technology in school is the time and effort needed on the part of teachers to develop the use of ICT in their teaching. Mariotti (2002, p. 720) describes this as '...a very expensive request....' and Tooke (2001, p.4) says that it is a '...slow process and is full of plateaus where little or no progress is noted.' Weist (2001), Cuban (2001), Stoddart & Niederhauser (1993), Glover & Miller (2001) and BECTa (2003a) all make specific mention of the time necessary for teachers to develop the skills and abilities to use technologies effectively in their teaching.

Other practical factors affecting the use of ICT include a lack of suitable software (Oldknow, 1998), availability of appropriate materials (Ruthven, 1993), unreliability (BECTa, 2003a and Cox et al, 1999) and poor design of equipment

(Cuban 2001). Several studies report that access to ICT resources is an issue for many teachers. Glover and Miller (2001) suggest that the teaching potential of ICT is only being fulfilled by those who have access to ICT facilities in their usual teaching rooms. Weist (2001) also says that teachers need convenient access to these resources in order to gain the confidence and competence necessary for teaching. Sutherland (1998, p.151) disputes these claims saying that whilst access is commonly given as a reason for the non-use of ICT, this is rarely the case because most schools in the UK are relatively well-equipped. Oldknow (1998) also notes that, in the English situation, there is competition between subjects for access to resources. There are therefore a number of possible explanations: teachers could be using lack of access as an excuse for not making more use of ICT in their teaching, there may be a genuine lack of resources in some cases, or perhaps it is the distribution of resources in schools that causes the perceived lack of access. Part of the data analysis in this study might shed light on this matter.

A number of researchers also report that the use of technologies in teaching and learning mathematics is inhibited by the lack of training available for teachers. Ruthven (1993, p.199) reports that, even after what he describes as 'very considerable effort at innovation in the UK' most teachers still lacked the training and resources needed. Stoddart & Neiderhauser (1993) also report a lack of effective training and that funding is often spent on purchasing hardware and software rather than in-service training. Ruthven and Stoddart & Neiderhauser describe the situation ten years ago but, more recently, Cuban (2001) reports that the situation remains one where teachers are not offered training at appropriate times and where they are offered generic training that was often 'irrelevant to their specific and immediate needs' (Cuban, 2001, p.98). In England, £230 million was spent between 1999 and 2003 on the New Opportunities Fund (NOF) training helping teachers increase their competence in using ICT for teaching and learning. Ofsted's (2002b) report on government initiatives in ICT reports that 'NOF training remains unsatisfactory in its overall effect' (Ofsted, 2002b, p. 3). So it seems that the training situation has not necessarily improved.

2.5.2 Attitudinal factors

A number of researchers report some teachers as having a range of negative feelings and attitudes (BECTa, 2003a) towards using ICT in their teaching. These feelings are often the result of some of the other factors listed previously. Cuban (2001) reports a deep ambivalence on the part of teachers about what computers can and cannot do and Kilpatrick & Davis (1993, p.211) report that teachers develop 'protective armour' against change, which they feel is inflicted upon them. Artigue (1998) makes a similar point, suggesting that teachers want to be convinced that changing their teaching will lead to increased efficiency. Simpson & Payne (2002, p.5) found evidence across six countries in Europe that where teachers saw themselves as '...serving only the requirement put upon them from elsewhere...' then they became reluctant learners. Glover & Miller (2001) also record teachers as feeling they must overcome feelings of ineptitude with technology and Guin & Trouche (1999) suggest that teachers appear to resist the integration of new technologies.

2.5.3 Complexity of technologies

Guin & Trouche (1999) and Balacheff & Kaput (1996) both comment on the complexities of the technologies used in teaching and learning mathematics. Guin & Trouche (1999, p. 224) say that the mathematical knowledge needed for efficient *instrumentation* (where the technology impacts on the user) is often underestimated by teachers. They also say that '...computer-based devices introduce a new source of knowledge transformation....' (p. 200). Balacheff & Kaput (1996, p. 470) cite the merging of graphical calculators and low-end computers and the merging of communications and interactive computation technologies as factors affecting the presence of technology in schools.

A number of researchers describe the need for teachers to have training in using the technology in its own right as a different issue to learning how to use the technology in their teaching. Mariotti (2002, p.720) says that teachers need '...a deep knowledge of the artefact...', Hedges et al (2003) that teachers need to become proficient in the technology and Glover & Miller (2001, p.268) the need for teachers to '...develop facility in the use of the technology'.

2.5.4 School factors and teacher accountability

Some researchers report organisational school factors adversely affecting the uptake of ICT in school mathematics. Stoddart & Neiderhauser (1993, p.16) say that '...the current emphasis on accountability ... has led to the development of 'teacher-proof' curricula'. Hannafin & Scott (2001) and Bottino & Furinghetti (1998), both mention that student assessment and the quantity of material to cover in the curriculum detract from the ability of teachers to develop the use of technologies in their teaching. These factors all describe the situation in English schools where frequent national assessment tests carry high stakes and therefore teachers are pressurised to cover a packed curriculum in ways that closely match the forms of testing used.

2.5.5 Changes in the role of the teacher

Many researchers develop themes in their work related to changes in teachers' role and the need for teachers to develop and change their pedagogies. Thomas et al (1996) are only one of those explicitly stating the difference between teachers having familiarity and experience with computers and having the ability and understanding to use computers effectively in their teaching. In order for the latter to occur teachers need to be flexible and to have self-confidence because this transition and development can be a difficult process (Leron & Hazzan, 1998). Leron & Hazzan (1998, p.202) also discuss the change in role for the teacher as from being '...the conveyor of knowledge...' to being '... a creator for action and reflection'. Balacheff & Kaput (1996) and Balacheff (1993) explain that this change cannot happen unless teachers understand the place and role of technology in the didactic process because traditional professional knowledge is insufficient in this regard.

Mariotti (2002) suggests that the emergence of new technologies should cause us to reconsider the difficulty of many of the problems used in mathematics teaching and that '...most traditional school activities should be reconsidered...' (p. 703). She goes on to say that we need a '...radical change of perspective and a profound change in the curricula...' (p. 720). Cuban (2001) approaches this same question from the opposite perspective when he says that most teachers continue to see computers as an add-on rather than as integral to their practice.

2.5.6 Summary

This section details a range of factors that impede many teachers in their ability to use technologies in their teaching. This could be considered to paint a rather black picture but it is heartening to note just how many teachers do make successful and innovative use of ICT in their teaching, and have come to an understanding of a new kind of pedagogy in their work, despite all these factors. What this section also shows us is the need to work with the complexity of the situation teachers face when seeking to integrate ICT in their teaching, and to acknowledge the difficulties they face as well as the imperative to help teachers develop new pedagogies with which to work. Simpson and Payne (2002) summarise the situation well when they say:

> The uses to which teachers will apply computers in their professional lives will depend on the extent to which they are confident in their ICT knowledge and skills and in the extend to which they have developed valued pedagogical uses for the technology' (p.27)

It is the necessity for a new pedagogy that forms the focus of the next section.

2.6 Pedagogy and Teacher Change

Many researchers document the tendency of teachers to fit the use of technologies into their existing pedagogy. Neiderhauser & Stoddart (2001, p.16) put this as teachers tending to use technology in ways that are '...consistent with their personal perspectives about curriculum and instructional design' and Ruthven (1993, p.190) describes this as '...the long tradition of adapting new technologies to an instructional tradition'. This predilection for teachers to continue with familiar ways of teaching and learning is also reported by Hoyles (1993) who says that teachers are constrained by curricular forces that mean that they do what they are used to doing.

Ruthven (1993, p.200) is rather pessimistic about the ways that educational innovations are often introduced. He says that it tends to be '...pragmatic, opinionated, commonsensical and mostly ineffective'. He says that this leads to a '....crude but robust system of classroom pedagogy...' which is '...largely incapable of fundamental change since there has been little accumulation and systemisation of knowledge to provide firm foundation for development'.

In the USA, the use of technologies in secondary mathematics teaching has been part of a reform movement aiming to move teachers from behaviourist to more constructivist views of teaching and learning (see Neiderhauser & Stoddart, 2001). The use of computers for 'drill and practice' or 'skills transmission' is seen as unhelpful and continuing the promotion of behaviourist approaches. Conversely, the use of 'open-ended' software is seen as supporting the development of more student-centred and constructivist approaches to learning mathematics.

What underlies these developments and the corresponding concerns is research that suggests that teachers use technologies differently depending on whether they have a behaviourist or constructivist approach (Wenglinsky, 1998; and Neiderhauser & Stoddart, 2001). Neiderhauser & Stoddart (2001) describe research that suggests that teachers shift towards the use of open-ended software as their beliefs becomes more constructivist in nature. Hence, they go on to report that teachers beliefs must not be ignored and that changing teachers' conceptions of the teaching and learning process is a key part of encouraging teachers to use technologies in their teaching. Weist (2001) reports similar findings suggesting that it is the ways in which computers are used that is important rather than how frequently, and that teachers need to focus on developing higher-order use of computers. These finding match those of Wenglinsky (1998).

3. Theoretical frameworks and research methodology

In seeking to plan this study there are a range of questions to consider in selecting suitable research methods and frameworks. These relate to ensuring that the methods chosen and decisions made directly relate to the research questions being asked. There are other factors and constraints to consider as well, including practicalities such as timing and timescale and appropriate choices of sources of evidence.

The literature survey and my research questions suggest that a multi-method approach will be both suitable and necessary for the data collection and analysis part of this study. The quantitative and statistical methods of a survey will allow me to consider facts, to have an objective approach and to collect data in a structured way from a larger number of subjects with the possibility of some generalisation. Qualitative methods should provide a complementary approach enabling me to search for meaning, to understand feelings and behaviour and to investigate complexities in a flexible way. Robson (1993) confirms that this is an appropriate way forward and that combining case-study and survey methods can be a useful approach. Cohen & Manion (2000) also suggest that this approach is particularly appropriate for the investigation of complex and controversial situations and where a holistic or broad view of an educational issue is needed.

3.1 Theoretical frameworks

3.1.1 Selection of a theoretical model

Researchers offer a range of models for considering the types of computer software used by mathematics teachers. Niederhauser & Stoddart (2001) offer a model classifying software first by distinguishing between behaviourist and constructivist philosophies:

Skills-based transmission software:	Drill-and-practice
	Keyboarding
Open-ended constructivist software:	Interactive/Educational games
	Exploratory
	Productivity/Presentation tools

Niederhauser & Stoddart's (2001) model is similar to that proposed by Hannafin & Scott (2001) but they add an intermediate category between the two labelled 'instructivism'.

Weist's (2001) model makes a different basic division, which is as follows:

Tools software:	
An aid towards another goal	
Instructional software:	Drill-and-practice
Designed to teach skills and concepts	
	Problem solving
	Simulations
	Games

This model is similar to that developed by Battista (2001) which offers three categories: general technical tools, technological tools for doing mathematics and computer environments. McCoy (1996) also has a model with three basic categories: programming, computer-assisted instruction and tools.

Other researchers note the limitations of models based on a small number of distinct categories and suggest models based on a continuum. These models also move away from considering the type of software in isolation from its classroom context to the consideration of other factors as well. For example, one such model is offered by Sutherland (1998, p.152) as a continuum ranging from '…the more open micro-world-type environments to the more closed intelligent learning environments.' Balacheff (1993) suggests classifying software along a continuum depending upon the degree of initiative that a student is allowed to take.

Balacheff & Kaput (1996) also describe a continuum based on the degree of didactic directedness of the software.

There are several disadvantages to such an approach. One is that these models tend to focus on categorising the software rather than exploring the uses teachers make of it. Another is, as Ruthven & Hennessy (2002, p.84) note, that this kind of approach tends to place constructivist and didactic pedagogies in opposition, and therefore seems to over-simplify. This is also an area where there may be noticeable contrasts between American and English practice, so I have decided to use a model derived by English researchers. This model is developed by Ruthven & Hennessy in their 2002 paper 'A Practitioner Model of the Use of Computer-Based Tools and Resources to Support Mathematics Teaching and Learning'.

My purposes here are two-fold. Firstly to see where data from my two mini case studies supplies evidence for Ruthven & Hennessy's twelve themes and secondly to see if I have any data that suggests amendments or additions to these themes. Rutheven & Hennessy's model is developed from data collected in the year 2000. Three years later, there have been changes in technology in secondary schools, for example, increased levels of use of interactive whiteboards. Ruthven & Hennessy (p.51) also say that their model is '...perhaps particular to place and period' so the examination of my data for amendments and additions to their themes is important.

3.1.2 Ruthven and Hennessy's model

This model is based on data collected from group interviews with seven school mathematics departments. It was then analysed to produce a thematic framework consisting of ten 'operational themes' and two 'pedagogical themes' describing teachers' views about the successful use of ICT to support the teaching and learning of mathematics. The themes are listed in the table 4 below (operational themes first):

Theme	Outline details
Ambience enhanced	'change, difference or variety' (p.65)
Restraints alleviated	'alleviation or mitigation of factors restraining or inhibiting the participation of students' (p.66)
Tinkering assisted	'the provisionality of many ICT results assists forms of tinkering to improve them' (p.68)
Motivation improved	'motivation of students towards classroom work' (p. 68)
Engagement intensified	'deeper and stronger student engagement' (p. 69)
Routine facilitated	'facilitation of relative routine components of classroom activity…. more quickly and reliability, with greater ease, and higher quality' (p.71)
Activity effected	'securing and enhancing the pace and productivity of classroom activity as a whole' (p. 70)
Features accentuated	'provision of vivid images and striking effects through which features of mathematical constructs…are accentuated' (p.72)
Attention raised	'reducing or removing need for attention to subsidiary task…avoiding or overcoming related obstacles' (p.73)
Ideas established	'formation and consolidation of ideas' (p.74)
Investigation promoted	'investigative approach to developing mathematical ideas, ….technology may play an important part in promoting such an approach' (p. 78)
Consolidation supported	'practice', 'reinforcement', 'revision of mathematical knowledge and skills' (p.78)

Table 4: Ruthven & Hennessy's themes

3.2 Research methodology

3.2.1 Research questions

The study here is intended to find out, for the defined set of schools taking part in the survey:

- What software and hardware mathematics departments use;
- How frequently they use them;
- What impact they think it is having on teaching and learning; and
- What they are using it for.

Two mini-case studies will provide additional data towards answering these questions and to finding out more detail about two teachers' practice in using ICT to teach mathematics.

3.2.2 Survey method

The first part of the data collection will be by survey. This will allow me to collect largely quantitative data at a 'single point in time', which can then be used for comparison. By basing the questionnaire on the Fischer Trust (2002) survey I hope I will also be able to compare my data with the results of a national survey. A survey will allow me to collect data in order to describe what is currently happening in schools, and possibly to generalise as well. Data collection by survey has the advantages of being controllable and focused on the research question by design. Surveys are also quick to administer and can be adapted for the specific purpose. Using a survey also allows me to use the same instrument with all participants whilst making efficient use of my time. However, there are clear disadvantages to this data collection technique as it will be difficult to get much detail from respondents. I cannot be sure that they will all interpret the questions the same way, and there are well-established limitations to using this from of self-reporting (Quinones & Kirshstein, 1998; Newell, 1993; Robson, 1993; May, 2001). Alternatives might include administering the questionnaire through groups, but experience suggests that it would be impossible to get more than a very few teachers together specifically for this purpose, and that attendance at a suitable meeting where I could do this would also limit the response rate.

The design of a suitable survey form will also mean that much of the data can be pre-coded (for the closed questions) and then analysed by computer. What the survey data will not be able to do is to provide evidence of causal connections as it will only be able to indicate associations. It is also important to bear in mind that it can also only sample opinion at a particular point in time. This however, is entirely adequate for the purpose, given that the use of ICT in schools is an area of rapid change, as discussed previously.

The survey will be piloted in order to test the data collection tool, the pre-coding and to carry out some sample data analysis. This will also allow me to test the Fischer Trust (2002) data collection tool to see if it meets my needs and to adapt it if necessary, as recommended by Quinones & Kirshstein (1998, p.28).

Robson (1993, p.150-151) and May (2001, p.108) both include specific advice about gaining a good response on a postal questionnaire, including advice about design and mailing. This advice was followed with the survey mailed out to named contacts in schools, followed up by a repeat mailing to those who did not respond the first time and a final pick up of those not responding at a meeting scheduled (for a different purpose) a few weeks later. This should help to maximise the return rate and because those receiving the survey already work closely with us in teacher training I hope they will be keen to participate. I expect by these means to have a high response rate. I have no intention of spitting the sample up further to analyse sub-samples, so I have no need to ensure that any sub-samples are of sufficient size for analysis.

3.2.3 Case studies

A case study approach was taken for part of this study to complement the survey data, an approach supported by Punch (1998, p.156). This will allow a detailed investigation of a smaller part of the evidence. Punch (1998, p.152) defines a case as '…a phenomenon of some sort occurring in a bounded context'. He further describes it as an inquiry where multiple sources of evidence are used to study a complex contemporary phenomenon in a real-life context (p. 152-3). A similar description is given by Robson (1993, p.52). This describes part of my study well in that the use of ICT in teaching and learning is a very relevant high stakes issue and the technology used by the two teachers is new and not always well understood. I describe the two case studies here as mini-case studies because they are short and are composed of data from only two sources, the observation of one lesson and a short interview.

3.2.4 Observation method

Choice of observation as a data collection method for the case studies was important because it allowed the data collection to be grounded in observed, rather than reported practice. It is also a way of collecting data that is not onerous on the subject, which is important when collecting data from teachers. Robson (1993) also describes observation as being useful for events that take a reasonably short time or that are frequent, and for activities that are accessible to observers. This makes it an appropriate method for my purposes. However, it only allows us to collect a part of evidence in that we can only measure what we can see and it is time-consuming for the researcher (Quinones & Kirshstein, 1998, p.30). Burgess (1984, p.96) quotes Spradley (1980) as suggesting three types of observation: descriptive, focused, and selective. The intention here is to use descriptive observation and, as recommended by Burgess (1984), to describe the setting, the people, and the events taking place. He goes on to say that observation gives the researcher the opportunity to gain accounts of situations in the participants' own language.

My role in the observations undertaken will be as an observer-participant (Burgess, 1984), or marginal participant (Robson, 1993), in that I will not distance myself as far as being solely an observer, but that the needs of the observation will have a higher priority than those of being a participant. This fits appropriately with being in a classroom, where pupils are very aware of the different roles of the adults around them.

3.2.5 Interview method

The use of interviewing as a method here is complementary to that of observation. Its disadvantage is that it relies on the teachers' reports of their own behaviour and not their actual observed behaviour (Robson, 1993, p.191 and Powney & Watts, 1987, p.190 both note this as a common discrepancy). It is also time-consuming and can be subjective in interpretation. What, however, an interview does offer is an opportunity to explore issues in more detail and to ensure that the questions have been interpreted as intended (Quinones & Kirshstein, 1998, p.32). The interview approach here is semi-structured with the intention of providing a structure to keep the interview on track and to ensure that the two interviews cover the same ground but at the same time to allow flexibility in following up issues raised during the interview (Fielding, 1993). The interviews will be carried out in an empty classroom immediately following the lesson observation and are intended to last approximately 20 minutes.

3.2.6 Triangulation

One of the reasons for the multi-method approach used here was for triangulation purposes. As Denzin (1997) says, every research method has its inherent weaknesses and '...no single method will ever capture all of the changing features of the social world under study' (p.310). Denzin (1997) describes five basic types of triangulation. Those used in this study are data, methodological and member-check triangulation. The two case studies allow for the checking of the survey data against observed data and against interview data, where more detail can be obtained and it is possible to explore teachers' understandings in more depth. On carrying out the study it was clear how the survey data provided one perspective, which was enriched and enhanced by the majority of respondents by the additional comments they added to it. However, as the data was analysed it became obvious that the case study data provided something complementary but quite different to the survey data, but that neither stood well alone.

3.2.7 Validity and Reliability

There are two main approaches to the questions of reliability and validity, depending whether the study uses quantitative or qualitative data. A number of researchers argue that the traditional terms 'validity' and 'reliability' used for positivist quantitative studies are not appropriate for newer designs and methods using qualitative data. Pirie (1998, p.159) says that there are no neat textbook methods or arguments by which qualitative research can be judged. As indicators of 'trustworthiness', Creswell (1998) credits Lincoln & Guba with the following indicators for qualitative studies: 'credibility', 'transferability', 'dependability' and 'conformability'. Creswell (1998) goes on to say that both dependability and conformability are established through an auditing of the research process. A similar approach is attributed to Eisner by Creswell (1998). This has credibility established by structural corroboration, consensual validation and referential adequacy. Pirie (1998, p.159-160) also says that all research should be judged by the goodness of fit of the research design and that qualitative research should be carefully reported both in terms of the design and in making explicit the subjective nature of the researcher's role in collecting and analysing the data. In the following sections, validity and reliability are considered in traditional terms for the quantitative part of this study before additional considerations are made for the case studies.

3.2.8 Validity for the survey

One of the key issues in designing the data collection for this study was to ensure that the tools used collected the information intended – in other words that the data collection was valid. The literature reviewed earlier confirms how difficult impact is not only to measure, but also to define. This matter was of particular concern to me, particularly in the questionnaire where it wouldn't be possible to ensure participants understood the questions correctly. I tackled this is by developing my questionnaire from an existing tool, piloting it twice and also by taking the advice of a small group of colleagues. An extensive reading of the literature beforehand, including the results of a similar survey, allowed me to check the survey for face validity. Anderson (1998) confirms that this is an appropriate approach for questionnaires. In terms of external validity the sample has been carefully defined and I will be taking great caution in generalising from it.

3.2.9 Reliability for the survey

The reliability of the questionnaire is determined by how consistently the questions would be answered if the data collection were repeated (Anderson, 1998) and the attention to detail taken in the planning and delivery stages makes the claim for reliability (Gilbert, 1993, p.99). Despite not having multiple choice questions (which have a high degree of reliability) the end points of the response scales were clearly labelled and should ensure a good level of reliability.

3.2.10 Case studies

This study contains detailed information about the collection and analysis of the case study data, which is contained within the Appendices. One reason for this is to support a claim that this research is meaningful and the conclusions from it are worth consideration. It also allows for the auditing referred to earlier. It creates a case for verification by creating what Anderson (1998, p.63) calls a '...chain of evidence...' and allows for Creswell's (1998) suggested procedures of peer debriefing, rich thick description that allows the reader to consider transferability for themselves and external audit. These are supplemented by the provision of Sturman's (1997) suggestions for credibility, which include explaining procedures, documenting analysis, distinguishing between sources of evidence and tracking the work done in the study.

Anderson (1998) further suggests that replication, one way of assessing reliability, is difficult for case study data. The use of the same interviewer and observer for both case studies, along with an interview schedule and observation protocol all support the reliability for my data collection. Case study, Robson (1993, p.160) asserts, relies on the trustworthiness of the researcher rather than on the data collection techniques.

3.2.11 Ethical considerations

Ethically, the study was carried out in accordance with departmental guidelines and following principles of beneficence, respect, justice, mutual respect, non-coercion and non-manipulation (as quoted by Simons, 2000). A covering letter (Appendix A) with the questionnaire ensured that participants understood the purposes of the data collection, the proposed uses of the data and that by participating they were giving their informed consent. For the case studies, the agreement of the teachers was sought verbally, by email when confirming arrangements and by formal letter to their Headteacher. This was considered to be the most appropriate way forward with partnership schools (note the advice of Burgess, 1984, and Creswell, 1998, in this area). The teachers involved in the case studies were also offered the opportunity to have the data returned for checking. From an ethical point of view this will ensure that they have the opportunity to identify anything that they would like removed. Clearly irrelevant social interaction in the interview was ignored in analysis, particularly that occurring at the beginning and the end of the interview.

It was particularly important at all stages to emphasise that the data collection would be confidential and confined to the study. This is because all the teachers taking part work with the university as partners in initial teacher training and it was important for all those involved to understand that their responses would not have any bearing on future placements for trainees.

Respondents to the questionnaire were asked to put their name and school on top of the questionnaire for the purposes of tracking responses. Schools and teachers have been anonymised in this study and care has been taken to ensure that no school or teacher is identifiable.

4. Data Collection

4.1 Sample

Those schools surveyed are all those schools working in partnership with a university in initial teacher training who offer a placement for secondary mathematics. This identified 38 schools for receiving the questionnaire, spread over a geographical area across South Central England and including schools with a wide variety of characteristics: beacon, specialist, church schools, rural, urban, inner city, single sex, mixed, 11-18, 11-16 and 13-18 age ranges. The questionnaires were sent to the mentor in the mathematics department by name with a stamped addressed envelope enclosed for return. This allowed the questionnaire to be sent to a named member of staff, who was likely to be an experienced teacher, as the mentor is usually either the head or second in department.

The covering letter with the questionnaire asked for returns by a specified date and the survey was timed carefully so that all the data, including the case study data, could be collected during the summer term 2003. This also allowed for a second follow up questionnaire to be sent and returned before a meeting for mentors held towards the end of the summer term, which would provide an opportunity for a final sweep up of respondents. A sample covering letter is in Appendix A and follows the advice given in Newell (1993).

4.2 Questionnaire design and trialling

Two versions of the questionnaire were trialled. The first was a straight copy of the Fischer Trust (2002) questionnaire reproduced in Appendix B. This allows respondents free choice as to which resources to list under the headings: software, web sites, specialist peripherals and communications. Each resource listed was given a score for frequency of use and impact on pupils' learning in mathematics. They were also asked for an overall rating for Key Stages 3 and 4, and about software and hardware for whole class interactive teaching and a space for free comment.

The first version of the questionnaire was given to a group of teachers attending a course in using ICT to teach mathematics. The opportunity for free choice in which resources to comment on led to a huge range of resources from a group of 25 respondents. I also noted that not all of them completed the second side of the questionnaire and many did not supply the overall rating for web sites that was requested. It was also interesting to note that there was a wide range of response from those participating in the trial and this was useful in preparing me for possible ranges of response from the survey proper.

As a result of the first trial a number of modifications were made. The second version of the questionnaire (see Appendix C) was intended to fit all the questions onto one side in order to ensure it was completed in full. I also felt that it would be better not to offer different categories for teachers to list hardware and software under as these seemed artificial. I also became interested in asking teachers about the use made of the software and hardware as the lack of specific indication of this seemed to be a short-coming of the Fischer Trust questionnaire. I also felt that this would enable respondents to more clearly indicate where software was used for more than one purpose as I had become aware that this may well be the case. This second version was trialled on another group of teachers attending a training course. It was a noticeable improvement in terms of the quality of response from participants and the ease with which the data could be analysed when I tried some data analysis techniques on it.

Using this version as a basis, discussion with colleagues (as recommended by Newell, 1993) also led to some further refinement of my questionnaire. We discussed whether I should use impact or benefit and what was meant by impact. I decided to use impact as it is currently the term used and understood in this context. We also decided that it would be helpful to include a short list of suggested resources for rating followed by spaces for teachers to add more if they wished. This will help ensure replies across a full range of resources as well as giving an indication as to which resources departments had. It will also allow resources to be grouped according to generic type, which will help with analysis. A simple addition to the table in version 2 also allows people to indicate whether use is at Key Stage 3 and/or Key Stage 4. The list of resources was compiled using the Fischer Trust (2002) results and those items on the pilot questionnaire. It should be noted that CAS is not included, although a respondent could add it optionally if they wished. CAS is not allowed in examinations at GCSE and A level, which limits its use in U.K. schools, and is the probably explanation for this important tool not appearing in the Fischer Trust list or in my pilot studies.

The final questionnaire (Appendix D) essentially consists of two parts. The main one is a table listing some resources and asking teachers to provide an indication of the frequency of use and impact on pupil's learning in mathematics for each item, and some indication of the use made of the resource. The second question asks teachers to indicate how much positive impact they feel ICT has had on pupils' learning at each Key Stage in mathematics in their school. They are asked to indicate 'very little', 'some', 'significant' and 'substantial' for Key Stages 3 and 4 separately. The questionnaire also offers teachers the opportunity to add any relevant comments if they wish.

All the versions of the questionnaire contained closed questions with the opportunity for the respondent to make free comment if they wished. The inclusion of closed questions to allow for data to be collated, analysed statistically and compared. The opportunity to comment offered respondents an opportunity to give more extended responses and to offer any information they felt was relevant. This information will also enrich and enlighten the data analysis and provide some level of explanation for some of the responses.

The final version of the questionnaire was printed on A3 paper to enable the table to fit well on the paper and to help teachers complete it.

4.2.1 Resource ratings design

The final questionnaire was designed so that teachers could circle to indicate the frequency and impact rather than have to write the numbers in each time. This was a recommendation from colleagues who felt that this would make it easier to fill in. We also changed the scales so that they both ran from 1 to 4 (instead of one running from 1 to 3) and only provided definitions for the end points of the scale.

4.2.2 Impact at Key Stages 3 and 4

The final question was designed to see if there was any difference between the two Key Stages. It might be, for example, that if there is lower impact at Key

Stage 4 then this could suggest that there is a more 'exam-oriented', didactic or 'drill and practice' curriculum for older pupils.

4.3 Case Study Design

I decided to select teachers who were using some kind of ICT frequently for the mini-case studies for two reasons. Partly for practical reasons, because this maximised the opportunity to observe a lesson using ICT, but principally because it allowed me to pursue particular aspects of the study relating to changes in teachers' practice and perceptions of the impact of ICT on teaching and learning. The bounds of the cases are clear in that they are about a single teacher's practice in their classroom using ICT to teach secondary mathematics and the benefits that they believe result from this.

Six teachers in the survey reported a high level of use of at least one resource in most lessons. One of these was discounted for the purposes of a mini-case study as the resource in question was a revision package and the teacher was due to go on maternity leave shortly. Of the remaining five, four reported substantial impact of ICT on pupils' learning at both Key Stages and the other teacher reported significant impact of ICT. All four indicated use of a data projector in most lessons, and three of an interactive whiteboard. Two of the teachers were selected, one of those reporting substantial impact of ICT at both Key Stages and the one reporting significant impact. Both were selected as teachers using interactive whiteboards, partly so that there would be some commonality between the case studies and partly in order to collect some data on what is a relatively new resource in schools. The selection of case studies on the grounds that they are the cases that offer us most opportunity to learn from is supported by Stake (1994, p.243) and Creswell (1998, p. 120). Simons (1996) describes case studies as opportunities to celebrate the '...particular and the unique...'. The inclusion of more than one case study allowed for the possibility that the teachers might offer different experiences for analysis, as was the case.

The additional data collected from the two teachers forming the mini-case studies consists of a lesson observation and a short interview. Following Creswell's (1998, p. 125-6) and Robson's (1993) advice, the lesson observation was designed to be a written account of the lesson in terms of what the teacher was doing, what the pupils were doing, the uses of ICT observed and a note of any of the physical issues relating to the use of ICT, for example, room layout constraints. I intended also to try and capture some phrases from the lesson verbatim. The teacher was then interviewed immediately after the lesson, as described below.

4.3.1 Interview Schedule

A semi-structured interview design was chosen to balance the need for collecting similar data from both teachers and, at the same time, allowing flexibility to follow up issues raised both in the lesson observation and during the course of the interview. The questions were chosen specifically to help the teacher articulate aspects of their practice relating to the use of ICT in their teaching and to encourage them to supply specific examples relating to this and following advice in Burgess (1984, p.111-112) and Robson (1993). They were therefore asked questions about:

- The choices they made in planning lessons;
- What benefits they believed ICT had in their teaching;
- Why they used ICT in their teaching;
- What would be different about their lessons if they had not used ICT; and
- How ICT helped their pupils learn mathematics.

The interview schedule is in Appendix E. The lesson descriptions and the transcribed interviews are in Appendix F.

5. Data Analysis for questionnaires

33 out of the 38 questionnaires were returned, a response rate of 87 %. This is high, particularly considering that May (2001, p.97) suggests a response rate of 40% is not uncommon. With this, and the range in variation of response from those teachers who did return their questionnaires, it did not seem necessary to specifically follow up any of those who did not respond to check for participation bias.

Initially the data was tallied onto a master copy of the questionnaire to get a feel for the data and to check its quality. A small number of returns contained minor errors that were probably the result of the respondent losing their place in the table but these were not deemed to have a significant effect on the survey outcomes. One school returned only frequency of use ratings and no impact ratings. No questionnaires were illegible or returned in an otherwise unusable manner. Responses indicate that teachers were willing to answer the questions and did not feel that the questionnaire was onerous or intrusive, or that any of the questions were obviously ambiguous. Generally, all the questions were answered by all respondents, which was encouraged by the simple questionnaire design with core questions and then the opportunity for some respondents to offer more detail if they wished. In these ways the survey counters the kinds of criticisms of postal questionnaire methods listed in Newell (1993) and Robson (1993).

5.1 Techniques used

Data on the frequency of use and impact rating from the questionnaires was transferred to an Excel spreadsheet, using a worksheet for each resource, for analysis first as univariate data and then as bivariate data. Where schools indicated that they had no access to a particular resource by either leaving the item completely blank, or by making a note indicating this, no entry was made. At this stage, incomplete data pairs (i.e. where one of the two scores were missing) were included. This data formed what is referred to in Appendix G as the 'Full data set'. Where a respondent indicated a score across more than one value, the mean was used, so for example, a response of 2 – 3 was given a value of 2.5.

The data for frequency of use and impact was grouped using the histogram feature in the Excel analysis toolkit and added to the worksheet. This grouped data was then used to produce a comparative bar chart for frequency of use and impact on pupils' learning in mathematics. Both Procter (1993, p.243-4) and Rosier (1997, p.160) note that frequency distributions are useful early on in the data analysis for providing the researcher with a first look at the data, and also for identifying errors and keeping track of the data set as it is modified through analysis.

This full data set was used to calculate the mean, standard deviation, maximum and minimum scores. In order to calculate the correlation between the frequency of use and impact scores the data set was amended by removing the incomplete data pairs. Note that Anderson (1998) confirms that researchers should make individual judgement calls in these cases and Robson (1993, p.315) says that there is no really satisfactory way to deal with it. These data pairs form the 'Amended' data sets in Appendix G. In one case, that of the interactive whiteboard, there were no incomplete data sets to remove. It is noticeable that there were more incomplete data pairs for the last two resources on the questionnaire (Logo and PowerPoint). This perhaps indicates that teachers were beginning to lose focus when filling the questionnaire in, or that they found it difficult to follow along the rows as they got further down the table.

Spearman's Rank correlation coefficient was used to calculate the correlation between the two scores in the amended data set. The key reason for choosing Spearman's Rank correlation coefficient over Pearson's correlation coefficient was that the data is not interval or ratio data. The data is given by ranking on a four point scale with the ends labelled as 'annually' and 'most lessons' the size of the gaps on the scale will not necessarily have been interpreted as equal by the respondents. The second reason for using Spearman's over Pearson's correlation coefficient was that Pearson's requires the data to be normally distributed and, as the histograms in Appendix G illustrate, this is not true for all the data sets. Spearman's Rank correlation coefficient is suitable for use with data that is not normally distributed, hence the choice was made.

The final part of this stage of the data analysis was to transfer the summary statistics, correlation coefficients and number of responses into a table (see table 5). All figures are given to three decimal places (more than sufficient for the purpose) and the percentages to the nearest whole number. This data was then ordered for comparative analysis to form tables 8, 9, 10 and 11.

Other data from the questionnaires, aside from any written comments, refers to the use made of the different resources. This information has been tallied and entered into table 6. The final part of the data to be tabulated is that giving an rating for the impact of ICT on pupils' learning in mathematics at both Key Stages. This has been tallied and totalled in table 7.

5.2 Results

Resource		Mean	Standard deviation	Maximum	Minimum	Spearman's Rank correlation coefficient	Percentage of schools using resource
Web sites	Frequency of use	2.063	0.704	3	1	0.752	100
	Impact	2.281	0.834	4	1		
CD ROMS	Frequency of use	1.768	0.726	3	1	0.877	85
	Impact	2.173	0.970	4	1		
Graphical calculators	Frequency of use	2.219	0.660	3	1	0.447	94
	Impact	2.786	0.860	4	1		
Interactive whiteboard	Frequency of use	2.381	1.045	4	1	0.767	64
	Impact	2.952	1.000	4	1		
Data projector	Frequency of use	2.400	1.131	4	1	0.848	76
	Impact	3.042	1.060	4	1		
Word processor	Frequency of use	2.269	0.710	4	1	0.351	79
	Impact	2.080	0.845	4	1		
Spreadsheet	Frequency of use	2.266	0.707	3	1	0.461	97
	Impact	2.807	0.780	4	1		
Dynamic Geometry software	Frequency of use	1.958	0.611	3	1	0.836	73
	Impact	2.891	0.978	4	1		
Graphing package	Frequency of use	2.096	0.620	3	1	0.408	73
	Impact	2.880	0.852	4	1		
LOGO	Frequency of use	1.381	0.575	3	1	0.420	73
	Impact	2.406	0.775	4	1		
PowerPoint	Frequency of use	1.865	0.673	3	1	0.818	79
	Impact	2.477	0.983	4	1		

Table 5: Summary of responses to questionnaires

	Whole class teaching		Pupil use		Lesson preparation and ideas	
Resource	Key Stage 3	Key Stage 4	Key Stage 3	Key Stage 4	Key Stage 3	Key Stage 4
Web sites	17	13	12	20	23	23
CD ROMS	13	12	9	5	15	13
Graphical calculators	25	25	24	22	9	9
Interactive whiteboard	17	16	10	11	8	7
Data projector	21	22	4	5	6	7
Word Processor	10	13	12	13	18	17
Spreadsheet	27	27	24	27	10	21
Dynamic Geometry software	20	21	14	15	12	12
Graphing package	21	22	17	17	11	12
Logo	18	5	17	4	6	3
PowerPoint	17	19	6	5	12	11

Table 6: Use made of the resources

	Very little	Some	Significant	Substantial
Key Stage 3	5 (15%)	8 (24%)	14 (42%)	6 (18%)
Key Stage 4	5 (15%)	8 (24%)	13 (31%)	7 (21%)

Table 7: Impact on pupils' learning of mathematics at Key Stages 3 and 4

Resource	Percentage of schools using resource
Web sites	100
Spreadsheet	97
Graphical calculators	94
CD ROMS	85
Word Processor	79
PowerPoint	79
Data projector	76
Dynamic Geometry software	73
Graphing package	73
Logo	73
Interactive whiteboard	64

Table 8: Resources listed in order of percentage of schools using them

Resource	Spearman's Rank correlation coefficient
CD ROMS	0.877
Data projector	0.848
Dynamic Geometry software	0.836
PowerPoint	0.818
Interactive whiteboard	0.767
Web sites	0.752
Spreadsheet	0.461
Graphical calculators	0.447
Logo	0.420
Graphing package	0.408
Word Processor	0.351

Table 9: Resources listed in order of correlation coefficient for impact and frequency of use

Resource	Mean
Data projector	2.400
Interactive whiteboard	2.381
Word Processor	2.269
Spreadsheet	2.266
Graphical calculators	2.219
Graphing package	2.096
Web sites	2.063
Dynamic Geometry software	1.958
PowerPoint	1.865
CD ROMS	1.768
Logo	1.381

Table 10: Resources listed in order of mean score for frequency of use

Resource	Mean
Data projector	3.042
Interactive whiteboard	2.952
Dynamic Geometry software	2.891
Graphing package	2.880
Spreadsheet	2.807
Graphical calculators	2.786
PowerPoint	2.477
Logo	2.406
Web sites	2.281
CD ROMS	2.173
Word Processor	2.080

Table 11: Resources listed in order of mean score for impact on pupils' learning in mathematics

5.3 Access to resources

The percentage of departments using each resource shown in table 8 indicates that all the schools who responded to the survey used web sites in their teaching and learning of mathematics. Virtually all used spreadsheets and the vast majority used graphical calculators. More than 75% had access to CD ROMS, word processing, PowerPoint presentation software and a data projector (but not necessarily all four). More than 70% had access to dynamic geometry software, a graphing package and Logo, and 64% had access to an interactive whiteboard. In fact, availability of a spreadsheet was 100% as the teacher who did not return any data on this resource said in a written addition to his questionnaire that he had made some use of one. It is surprising to see that only 73% of respondents reported any use of Logo given that there is a version (MSW Logo) which is available at no cost and because it is a very well established piece of software in mathematics education. Given that many departments reported having mathematics-specific software such as dynamic geometry software and graphing packages any infrequency of use of these items must be related to factors such as access, the training and confidence of teachers, and pedagogical decisions about suitability of use. These issues were not explored specifically in the questionnaire, although many respondents took up the offer of making additional comments and referred to these matters. These issues are, however, explored in more detail in the case studies that form part of this work.

Further to issues relating to access to resources, three teachers took the opportunity to specifically mention financial restraints, saying:

> *'Because of funding we don't have dynamic geometry, logo...'*

> *'...expense is a problem'*

and

> *'Financial restraints....plays a significant part in the effect of ICT...'*

Eight teachers took the opportunity to say that their use of ICT in teaching mathematics is limited due to lack of access to computers.

It is interesting to note, still on the issue of financial restraints, that one of the case study teachers perceived dynamic geometry software as cheaper than graphical calculator batteries. This was because the dynamic geometry software license had come as part of a large, expensive purchase of a commercial electronic scheme paid for centrally by the school. Funding for batteries for the graphical calculators was considered to be expensive because the department had to find this money from its own resources.

5.4 Analysis of tables

Most of this analysis will be carried out by looking at each resource in turn. This will allow a more holistic approach to the data and easier analysis of the interaction of the factors involved. The comments added to the questionnaires by the respondents and relevant comments from the two mini-case studies will be considered here as well. Table 10 contains the ordered list of the mean for frequency of use, table 11 the ordered list for the mean of the impact scores for each resource and table 9 the ordered list of Spearman's Rank correlation coefficient. None of the data in the tables should be disregarded on the grounds of sample size, particularly given the high response rate for the survey.

5.5 Frequency of use

Data projectors were the most frequently used resource followed by the interactive whiteboard. An explanation for this high ranking for the least common resource is that it was one of the very few resources any teacher reported using in 'most lessons' (along with data projectors). Most items were frequently used by some teachers, but the mean scores were decreased by the number of teachers reporting infrequent use of the same resource (evidenced by the maximum and minimum values in table 5 and the histograms in Appendix G).

5.6 Impact on pupils' learning in mathematics

The table for mean impact scores (table 11) shows high scores for several items. The two items most frequently used had the greatest impact (data projector and interactive whiteboard). However, word processing was the third most frequently used resource but was bottom for impact on pupils' learning in mathematics. In reverse, dynamic geometry software was less frequently used than many other resources but came third for impact. Impact scores, even for word processing, are above the score of 2, suggesting that all the resources listed had at least some impact on mathematics learning. Comparison with table 7, which shows the impact of ICT on pupil's learning overall in both Key Stages, suggests that, where ICT is concerned, the impact of the whole is greater than the impact of the parts. It is also interesting to note that all items scored across the whole range of possible scores.

5.7 Correlation between frequency of use and impact

In table 9 we can see that four items show a strong positive correlation between frequency of use and impact on learning. These are CD ROMS, Data projector, Dynamic Geometry software and PowerPoint. Explaining this relationship and considering any causality between the two quantities may not be straight-forward. The category CD ROMS covers a huge range of items so it may be that a higher frequency of use is reported by departments with a wide range of titles and that this, in turn, leads to greater impact. In the case of software such as that for dynamic geometry it may be that as someone uses the software more they find more benefits to using it and the impact the software has is increased. Two other items, interactive whiteboard and web sites, show a strong, but slightly less so, positive correlation. The remaining items show weak positive correlation between frequency of use and impact. In some cases perhaps frequency of use is not important and it is the pedagogic decisions teachers make about using the resource that are more important. It may be that the case studies will cast further light on these relationships. Care should be taken when interpreting scores for frequency of use and impact as the scales are different.

5.8 Analysis of individual resources

5.8.1 Web sites

All schools reported some use of web sites although none used them most lessons. The range of uses was wide and they were particularly used for lesson preparation and ideas. Comments from teachers indicated use for research, revision and to find up to date information.

5.8.2 CD ROMS

CD ROMS were one of the least frequently used resources and also had a low mean impact score. However, they had the highest correlation coefficient between the two scores, so their impact reflected the amount they are used. They are infrequently used by pupils and generally used for lesson preparation and ideas as well as whole class teaching at both Key Stages. This category covers a huge range of types of material including revision material, banks of past exam questions, small software, data sets for statistics, presentations and classroom resource material. Lack of use of CD ROMS in some schools may be explained by one teacher's comment that her school has a policy of disabling the CD ROM drives on the school PCs.

5.8.3 Graphical calculators

Graphical calculators are widely used by the schools in the survey on fairly infrequent basis. They are mostly used for whole class teaching and for pupil use with very little difference between the two Key Stages and there is only weak correlation between frequency of use and impact on pupils' learning. Teacher comments about this resource suggest that in some schools graphical calculators are used only for particular topics and that in others their use is more wide-ranging. One teacher, commenting on the problems they have with access computer suites wrote:

'Graphical calculators are a god send!'

5.8.4 Interactive whiteboard

Unsurprisingly, given their cost and only recent adoption by schools, interactive whiteboards were the least common resource available in schools. However, they had still been used in some way by 64% of respondents. The pattern of frequency of use is very broad but the pattern for their impact appears to reflect the two extremes of usage. Four teachers reported having using an interactive whiteboard for most lessons and therefore, presumably had one permanently set up in their classroom. Others reported less frequent use, perhaps where they shared one in the department or occasionally borrowed one from elsewhere in the school. 76% of those using this resource reported it as having an impact rating of 3 or 4. Hence, it became one of the most frequently used resources and one of those with the highest impact. The proportion of teachers giving a high impact score fits well with the findings of Smith & MirandaNet Fellows (2000) who reported all the staff in their study finding the interactive whiteboard effective in terms of learning gains.

The two mini-case studies indicate an emphasis on using this resource with commercially-produced resources designed specifically for this purpose, for example, Learnpremium (www.learn.co.uk), Mathsalive and Easiteach (both www.rm.com). The studies also suggest that teachers found that the interactive whiteboard offered them flexibility, increased pupil involvement, and that its use was particularly valuable for topics that suited a visual approach.

5.8.5 Data projector

Unsurprisingly, data projectors were almost always used for whole-class teaching. This use was spilt evenly between the two Key Stages. It is also unsurprising that more teachers had access to a data projector than an interactive whiteboard, given that you need the first to operate the second and that the second are often in fixed locations. Frequency and impact were similar to those from the interactive whiteboard results. The positive correlation between frequency of use and impact on teaching and learning mathematics was strong for data projectors. The distribution for frequency of use is bimodal, suggesting that schools either had little access or perhaps access to one projector in the department (the second peak is at the score of 3 not 4, suggesting perhaps departmental access rather than a teacher having permanent access).

One teacher responded very positively about the use of this technology:

> *'Using a laptop and digital projector as a whole class teaching aid is fantastic!.....The impact is huge in many areas.....'*

5.8.6 Word processor

79% of respondents indicated use of a word processor, with some comments indicating teacher use for producing documents such as worksheets and pupil use for producing reports (particularly coursework). Although use was fairly frequent compared with other resources, word processing software was given the lowest impact rating and had the weakest correlation coefficient for frequency of use and impact. Only one teacher reported using a word processor most lessons.

5.8.7 Spreadsheet

Spreadsheets were a resource used by all respondents (see section 5.3 for explanation of this statement). Table 5 and the written comments from respondents indicate that spreadsheets were used for a range of purposes in schools, both teaching and administrative. This is demonstrated by the teacher in the second mini-case study who describes using Microsoft Excel for number pattern work, grids and table squares, data handling work and drawing statistical diagrams. The teacher in the first case study also describes several uses for Excel, including with year 7 collecting and comparing data for a whole class survey. She also uses it with year 10 for GCSE coursework, both for pupil use in the computer suite and with the interactive whiteboard for demonstration purposes. This fits well with Bottino & Furinghetti's (1998) finding that spreadsheets have potential use in a number of topic areas. Ofsted (2002a) also report positively on the use of spreadsheet in mathematics saying that they make a '...positive contribution to achievement...' (p.18).

The higher number of teachers reporting use for lesson preparation at Key Stage 4 compared to Key Stage 3 may be a consequence of the new data handling coursework at GCSE. Interestingly, there is only weak correlation between frequency of use and impact on pupils' learning for spreadsheets which is in contrast to the reported findings above from Bottino & Furinghetti (1998) and Ofsted (2002a).

5.8.8 Dynamic Geometry software

Dynamic Geometry software had a lower mean frequency of use score than some of the other resources listed but came third in the table for impact and had strong correlation between the two scores. This is clearly shown by the histograms in Appendix G. The software use was evenly split between use at Key Stage 3 and 4 and was more often used for whole-class teaching than by pupils.

In the second case study there is an indication that the teacher was beginning to explore further the potential of this type of software as she says that she has used it for plotting functions and was intending to extend use to pupils using the geometrical facilities. This software is relatively new in secondary school classrooms in England and it is likely that many teachers are in the similar position of beginning to explore the potential of the software.

5.8.9 Graphing package

It was surprising to find that as many schools had Dynamic Geometry software as had graphing packages given that the use of the latter has been common in U.K. at lower secondary level for far longer. Use of these was by both teachers and pupils and was evenly split between the two Key Stages. There was only weak correlation between frequency of use and impact and 17 of the 23 responses rated graphing packages as having an impact score of 3 or 4. This may indicate that these types of packages are used for particular topics on a regular basis where they are considered to be beneficial to pupils' learning but that their use is not extended further (note that some of these packages may not lend themselves to other topics anyway).

5.8.10 Logo

Logo was the least-frequently used of the resources and there was only weak correlation between frequency of use and impact. This was the only resource reporting a significant difference in use between the two Key Stages with more use at Key Stage 3 (see table 6). 65% of users reported using Logo only annually. There may be a small clue to this lack of frequency of use of Logo in the second mini-case study where the teacher describes Logo as one of those 'old traditional things'.

5.8.11 PowerPoint

As would be expected, PowerPoint was mostly used for whole-class teaching. It was also used in almost half the replies for lesson preparation and ideas. This perhaps refers to teachers accessing and using or adapting PowerPoint presentations from sources such as published resources, the Internet or other teachers.

5.8.12 Other resources

Teachers were also given the opportunity to list other resources they used on their questionnaire. Some took up this opportunity, but most of these resources were not listed by any other schools. They were a range of specific web sites, hardware and software, some of which they rated highly.

5.9 Teachers' comments on the questionnaires

Thirteen of the respondents added comments to their questionnaires that gave further insight into pedagogy and support and development issues. For example, one teacher listed five ways in which he feels that the use of an interactive whiteboard is of benefit to his teaching. Others commented on their future plans for developing the use of ICT in their departments and two commented that ICT had most impact or use in lesson preparation. One commented on development issues saying:

> *'Where teacher ICT competence or confidence is high, use + impact is relatively high*
> *Where teacher ICT competence or confidence is low, use + impact is relatively low/poor'*

Another picked up this theme, saying:

'...teacher competency plays a significant part in the effect of ICT'

Some described the process by which they made decisions about choosing or using ICT:

'.....ICT is always used if relevant....'

'....considering a KS4 scheme that focuses on contextual learning – specially useful for foundation pupils'

'We do not follow the set lessons but pick out particular activities to enhance learning.'

One teacher made a point of expressing the current situation in his department saying:

'ICT in maths is very exciting and my staff are increasingly confident and enthusiastic'.

5.10 Impact on pupils' learning overall at both Key Stages

Table 7 shows almost no difference in the impact of ICT on pupils' learning between Key Stages 3 and 4. This suggests some level of equality of access between the two stages, although a more detailed investigation into the use made of ICT at the two Key Stages might find some significant differences between them. Given that the ImpaCT2 study (BECTa, 2002a) found that ICT use was rare in schools, and mathematics lessons in particular, at Key Stage 4 this is an interesting result and may indicate a change over time.

Four schools reported little impact of ICT at either Key Stage. These four returns are typified by either poor resourcing or poor access to those resources present in school. For example, one school only returned use and impact scores for Web sites (for pupil use only) and for an interactive whiteboard. One of the others cited access issues following from school policy by adding the following to the questionnaire:

'...we have 4 ICT rooms of roughly 30 computers in each. However they are usually booked for ICT or Tech lessons making it very difficult to get into......the only emphasis for ICT is on GNVQ ICT and nothing must upset this.'

And another had similar access issues:

'The biggest issue is availability. We have to book computer room and there are very few periods when it is bookable. We have to rely on Year 11 leaving to get into use. Before that is appalling. Even if you can book you will never be able to get a continuum of lessons!'

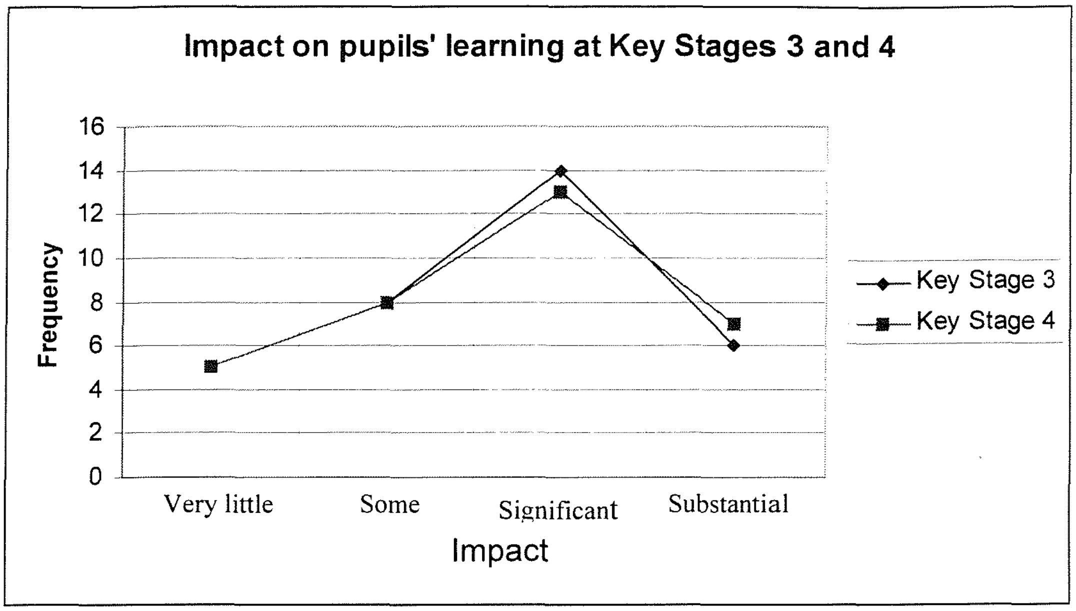

Figure 1: Graph showing impact on pupils' learning at Key Stages 3 and 4

The data for impact at both Key Stages has also been drawn as a frequency polygon in Figure 1 to allow the two sets of data to be superimposed and compared ('frequency' here indicates the number of responses, as distinct from the phrase 'frequency of use' used to analyse other survey results). This highlights the similarity between the two patterns and the positive skew the data has towards ICT having an impact on pupils' learning. Over 60% of schools reported that ICT was having a significant or substantial impact on pupils' learning in mathematics at both Key Stages 3 and 4.

5.11 Summary of findings from questionnaire

Key findings are as follows:

- For most software, other than Logo, there was equality of use between Key Stages 3 and 4;
- For some resources, there is a strong correlation between frequency of use and impact on pupils' learning (for example, CD ROMs, data projector, and Dynamic Geometry software;

- For other resources, there is a low frequency of use but high impact on pupils' learning (for example, graphing packages);
- There is variation in both the resources available and the ease of access across schools.

6. Analysis of mini-case studies

To aid analysis, the observation notes were typed up shortly afterwards and the interview data was fully transcribed from tape. Full transcription was needed in order to use Ruthven & Hennessy's (2002) model.

6.1 Techniques used

Creswell (1998) describes the process of analysing case study data as taking many forms in order to '...convey simultaneously breaking down the data and reconfiguring them into new forms' (p.20). Following this, the first part of the analysis of the mini-case studies here takes the form of pen portraits of the two teachers. These give a summary of the lesson observation and interview with each teacher and characterise each teacher's approach in order to set the scene for the later, more detailed, analysis.

The data was then examined under three headings looking for evidence about the following:

- The perceived benefits of using ICT;
- Changes in the teachers' pedagogy and practice as a result of the use of ICT;
- Additional evidence to add to that from the survey.

This organisation of the data fed into the following parts of the analysis. Here the model developed by Ruthven and Hennessy (2002) outlined in section 3.8.1 is used to explore teachers' views about the successful use of ICT to support the teaching and learning of mathematics. I examined my data for evidence supporting their twelve themes and for any evidence that proposed the existence of new themes. Afterwards, the data found for each theme was checked back against the transcript to see which phrases appeared in multiple themes and which data had not been allocated to themes at all. Data appearing in more than one theme were checked to see if this was correct. It is entirely reasonable for this to happen given that some of the themes are closely connected to others. Data not allocated to a theme at all was checked to see if it fitted one of the established themes or whether it formed evidence for the creation of a new theme.

All the mini-case study data was also considered to see how practice and pedagogy change as technology is employed. Ruthven and Hennessy (2002, p.85) note that their study provides some clues as to the ways in which pedagogy changes and develops with the use of ICT:

> What this study hints at is a gradual mechanism whereby teachers initially view technology though the lens of their established practice, and employ it accordingly. Even at this stage, however, shifts in practice may result….in which technology figures in teachers' thinking about their practice as a contributory, but subsidiary, factor. As well as serving as a 'lever' through which teachers seek to make established practice more effective, technology appears also to act as a 'fulcrum' for some degree of reorientation of practice, and a measured development of teachers' pedagogical thinking.

In these concluding remarks to their paper, the authors provide a basis for the the corresponding section of my analysis of my case study data in terms of a search for changes in pedagogy afforded by the use of ICT in teachers' classroom practice.

6.2 Pen portraits of teachers

The two teachers in this study are markedly different in some respects. Teacher A values ICT for its motivational value and for its ability to increase pupil involvement in lessons. Teacher B values ICT particularly in terms of it adding clarity and visual impact to her teaching and in terms of it adding multi-sensory, multi-media approaches to learning.

Both teachers have access to computer suites and have interactive whiteboards in their classrooms. However, there are marked differences in the provision of other resources in the mathematics departments of their schools. Teacher A does not have dynamic geometry software or Logo, whereas teacher B does. Much of teacher B's classroom use of ICT is based around an electronic scheme of work purchased by the school.

6.3 Perceived benefits from using ICT

Both teachers made many references to the benefits they saw from using ICT in their teaching. These are listed in Appendix H. Key themes in terms of the benefits of ICT related to the following:

- Opportunity for visual and multi-sensory approaches;

- Increase in pupil involvement through motivation, pace, competition and enjoyment;
- Ability to use alternative approaches and real-life examples;
- Support for classroom management by allowing the teacher to focus on the class.

6.4 Analysis using Ruthven and Hennessy's model

A full analysis of the interview data against Ruthven & Hennessy's themes is in Appendix I. Both teachers commented on being able to use ICT to add variety to their lessons both by increasing the range of materials used and by increasing the number of activities in a lesson, including the facility to use activities only for a short time. Both also mentioned using the computer suite, thereby changing the working space for pupils. They also both commented about the way in which ICT prevents 'work' becoming 'drudgery' (Ruthven & Hennessy, 2002, p. 66) with particular reference to graph sketching. Both teachers said that the use of ICT for such a purpose stopped pupils getting bored, 'bogged down' and stopped the activity becoming tedious. Teacher B also talked about the software for the interactive whiteboard alleviating restraints for her because it allows her to produce grids, axes and scales quickly and accurately, which wasn't possible before.

Only teacher A commented on the way ICT assisted pupils with tinkering. She provides a nice example of pupils being able to try things out and explore the consequences when she says:

> *...you can actually take twenty-five from both sides and they can see the equation getting more complicated without them having to actually go through and make the mistakes and putting the computer to do it correctly so that they can see what their mistakes will actually lead to.*

Unsurprisingly, both teachers make lots of comments about pupils enjoying working with ICT, using phrases such as 'they like that', 'they get quite interested', 'they appreciate', 'they want to have a go', 'they enjoy' and 'they are very keen'. Both teachers commented on the ways they see that ICT has increased pupils' engagement with mathematics, including comments about pupils 'going further' with their work that they would have done previously.

Both teachers, and particularly teacher A, commented on the way in which routine was facilitated by ICT. In the context of having interactive whiteboards in their classrooms both teachers particularly commented on how this use of ICT made things quicker for themselves in terms of whole-class. Teacher A also makes a number of comments about how ICT increases the pace and productivity of classroom activity generally.

Both teachers comment on the way that ICT accentuates features in their teaching. Teacher A talks about how ICT brings mathematics alive for pupils and that pupils are able to 'see' things happen. Teacher B comments quite fully on the way in which ICT allows her to add to the clarity of her teaching and on the way that colour can be used effectively to convey mathematical concepts. She also notes that ICT allows her to use other multi-media approaches, the use of sound, for example.

Both teachers comment on how ICT can raise pupils' attention to the mathematics they are studying using graph sketching as an example. Teacher A also makes some comments about how ICT supports the establishment of ideas in her teaching.

Of the two pedagogical themes proposed by Ruthven and Hennessy, teacher A makes a brief implicit reference to using an investigational approach to teaching mathematics using ICT and also talks about using ICT to support her 'icecream scoops' investigation. However, this is not in terms of ICT supporting the investigative nature of the work but that ICT allows her to revisit the work done in previous lessons and recap for pupils. Both teachers mention common investigations where they have used ICT to support the mathematics learning but do not comment on using technology to support such an approach explicitly. Both teachers mention the use of computer games to support consolidation and revision in their lessons. Teacher A's comments about the benefits of feedback have been placed in this category as this is a common feature of this type of software.

On a number of occasions, data fell into more than one theme and I allowed this to happen by entering it separately for both themes. It is not surprising this happened, given firstly that Ruthven and Hennessy comment throughout their work about the linked nature of several themes. Secondly, logic would suggest that, for example, engagement and restraints themes are linked to other themes because if pupils were engaged more, or if restraints have been overcome using ICT, then one would expect them to engage and achieve more in lessons.

6.5 Extension to model

There are a number of comments by both teachers in the case studies that do not fit well with any of Ruthven and Hennessy's twelve themes. Some of these comments relate to the use of an interactive whiteboard. This is technology that was rarely available in schools when Ruthven and Hennessy collected their data in 2000 and is not universally common at the time of writing (see survey data).

My case study data tentatively suggests the addition of three more categories to the twelve proposed by Ruthven and Hennessy. These are as follows with the data in Appendix J.

6.5.1 Using real life examples

Both teachers commented on the ability of ICT to support them in using real-life examples in their teaching. This could either be considered as a new category, or it could fit as an extension and development of the existing pedagogical category 'investigation promoted'.

6.5.2 Classroom management

Comments from both teachers indicate the value of whole-class presentation technology in terms of supporting classroom management in allowing them to face the class for more of the lesson.

6.5.3 Reviewing previous material

Teacher A comments on how her interactive whiteboard allows her to revisit work from earlier in the lesson and from previous lessons. In fact, this is more a feature of having lesson material in an easily accessible electronic format than of the interactive whiteboard in particular.

6.6 Changing Pedagogy and Practice

This section is in three parts. The first two give separate descriptions of the two teachers in terms of the evidence of technology changing their pedagogy and practice in the classroom. The final section links the experiences of the two teachers together.

6.6.1 Teacher A:

At the start of the lesson teacher A is switching at will between her interactive whiteboard and a more traditional roller whiteboard. She appears confident and competent with her technology as all her files are open and ready for use on the toolbar at the beginning of the lesson and during the lesson she switches seamlessly between them. She shows her confidence as well in the way that she adapts her lesson to follow lines of enquiry suggested by pupils, in particular when two pupils spontaneously make an implicit assumption about the line of reflection (see Appendix F).

She describes in the interview how she selects resources depending on the topic being taught and how she sees visual topics as being particularly suitable for use with the interactive whiteboard. She finds preparation in advance particularly useful when using the interactive whiteboard and considers that she needs to be well-prepared in order to make best use of resources. She concludes the interview by discussing the way that she may move to preparing all her lessons on the computer.

In her interview she describes how her new technology allows her to revisit previous lessons, go back a slide and so on. These are all practices that were difficult or impossible previously and mark both a change in her practice and a change in her pedagogy. She considers that this technology also allows her to increase the pace of her lessons, exploit the visual aspects of topics more fully, increase the variety of experience pupils have in lessons and decrease the volume of traditional written work carried out by pupils. Her reflections in the interview show her developing her practice and changing her pedagogy as she explores these new opportunities in her teaching.

6.6.2 Teacher B

One of the changes described by teacher B is the way that the advent of the interactive whiteboard and their new electronic scheme of work has led them as a department to rethink how they interact with pupils in the course of whole-class teaching. She discusses the problem they have had in that only one or two pupils can come up and touch the board during the lesson. This has led to two different solutions. One of these is the use of team participation, particularly with games in the plenary and starter activities. The second solution is evidenced by the extensive use she now makes of individual mini-whiteboards so that all pupils respond and contribute in lessons and marks a key change in pedagogy for her.

In the interview she describes how planning to use the interactive whiteboard takes her a long time so she is only able to use the technology if she has had proper time to plan the previous week. A significant part of her planning is making a choice as to what she will use from the electronic scheme of work they have purchased. During the interview she describes how she has adapted the file from the scheme by discarding the part that she feels is too difficult for the class.

She also tells how the department have begun to share resources more effectively between themselves through posting files on a shared area of the school network.

6.6.3 Common experiences

Both teachers tell stories related to a journey they are on with learning about using ICT to teach mathematics. More particularly, both were telling me about developing the use of their new interactive whiteboards. Despite prompting in the interviews, both kept returning to telling me about this one particular technology and found it difficult to talk more explicitly about a more integrated approach to the use of ICT in teaching and learning mathematics..

There are three commonalities between these stories.

- Increased time spent on planning and a change in the way planning is carried out;
- Increased sharing of resources and ideas across the department; and
- Changing ways in which they are interacting with pupils.

7. Discussion

In the first part of this section my survey data is compared with that of the Fischer Trust (2002). The discussion then moves on to consideration of the questionnaire, the case studies, and then the study as a whole before closing with the limitations of the study.

7.1 Comparison with Fischer Trust data

As mentioned earlier, comparison was one of the original intentions of this project. However, the trialling process let to a number of significant modifications, which make this impossible in some cases.

7.1.1 Impact ratings

Item	Impact rating
Interactive whiteboard	3.6
Autograph (graphing and statistics)	2.9
Successmaker (ILS)	2.9
Graphical calculators	2.8
Omnigraph (graph plotting)	2.7
BBC Bytesize website	2.7
Microsoft Excel	2.3
Coypu (graph plotting)	2.3
The Geometer's Sketchpad	2.3
Cabri Geometre II	2.3

Fischer Trust Survey: Resources listed in order of impact rating (top ten only)

Resource	Mean
Data projector	3.042
Interactive whiteboard	2.952
Dynamic Geometry software	2.891
Graphing package	2.880
Spreadsheet	2.807
Graphical calculators	2.786
PowerPoint	2.477
Logo	2.406
Web sites	2.281
CD ROMS	2.173
Word Processor	2.080

My Survey: Resources listed in order of mean score for impact on pupils' learning in mathematics

Table 12: Tables 1 and 11 are reproduced above for convenience in comparing the impact ratings given in the Fischer Trust survey and in my survey.

Common features between the two surveys are that the interactive whiteboard scores highly in both surveys and that spreadsheets and graphical calculators appear mid-table in both. A noticeable difference is that Dynamic Geometry software scores highly in my survey but is ranked bottom and next-to-bottom in the Fischer Trust survey. This difference may have arisen in several ways. First, it is possible that there are local conditions that mean that schools in the university partnership are using Dynamic Geometry software more than schools in other parts of the country. It may alternatively, or additionally, be that the use of this software is a very recent development and post-dates the Fischer Trust survey.

Another noticeable difference between the two is that Successmaker (ILS) is ranked highly in the Fischer Trust survey but does not appear in mine. This may, in part, be a consequence of the smaller sample size in my study.

Further comparison is difficult because the items are not identical in that the Fischer Trust is brand-specific and in my survey I gave the teachers more generic names. This came about as a result of the trialling of my first and second versions of the questionnaire, which had the consequence of making the results less directly comparable.

7.1.2 Measure of availability

It is difficult to make meaningful comparison between tables 2 and 8. This is because, although the Fischer Trust survey indicates the number of responses for each item, there is no total to work with. There is no total because in this survey schools were allowed free choice as to which resources they mentioned, and may not have mentioned all those resources they possessed. Although the survey includes data from 314 departments the survey covers two years so some departments may have responded both years.

It is, however, noticeable that the schools in my survey all had access to a wide range of resources whereas the Fischer Trust survey shows high response rates only for Microsoft Excel, Logo, Omnigraph and SMILE mathematics (but we do not know what proportion of schools these response rates represent).

7.1.3 Frequency of use ratings

It is difficult to compare tables 3 and 10, which show the frequency of use, in any meaningful way. This is for all the same reasons as mentioned, in that the Fischer Trust data in this area is not ranked, as mine is.

7.2 Discussion relating to questionnaire

One very noticeable outcome of the questionnaire is the variation of responses from schools. This is demonstrated in several aspects of the survey. The availability of ICT resources is clearly very variable in that some mathematics departments are clearly well-resourced with good access to some or all of: computer suites; whole class projection equipment; graphical calculators; and other hardware and software. Other departments clearly expressed frustration about lack of access to ICT resources and their sense of having to 'compete' with other departments for access to computer suites, for example. Several respondents made it clear that the questionnaire was from them personally and did not reflect the use made of ICT in the department as a whole. This fits well with the finding from Ofsted (2002a) and Cuban (2001) about the lack of consistency across departments, and by Simpson & Payne (2002) about variation within schools. The other indicator as to the variation in responses across departments is shown in summary table of questionnaire responses (table 5). For every entry, the range of scores for frequency of use and impact is either 2 or 3, out of a possible 3 (the values must be within the range 1 to 4). Hence, for all questions, at least one department scored it highly with a 3 or 4 and at least one scored the same item with a 1. This does not seem to be a feature of solely local, or even possibly, national experience. According to Simpson and Payne (2002), huge variation in forms of professional development, the reaction of teachers to this training and the subsequent use made of technology is a noticeable feature in the introduction of ICT in schools across Europe.

Many mathematics departments in the survey seem still to be battling with practical and pragmatic issues such as room layout, access to computer suites, purchase of software and provision of training. This fits well with the findings of Glover & Miller (2001), Weist (2001) and Oldknow (1998), for example, quoted from in section 2.5.1 and suggest that my findings are in line with other studies.

7.3 Discussion relating to mini-case studies

Both teachers in the case study had interactive whiteboards permanently in their classrooms and reported a high level of use and impact for this technology. This is supporting evidence for the views of Glover & Miller (2001) and Weist (2001) about the importance of ease of access to resources in leading to teacher competence, confidence and effective use of ICT in teaching.

One of the themes emerging from the case studies is that the increase in pace in lessons using whole-class presentation technologies may be the result of changes in the way lessons are planned when teachers have access to such technology. Both teachers comment on changes in the way they prepared their lessons because they needed to select, develop and plan the use of suitable materials in advance. Glover & Miller (2001, p.261) also find that lesson planning '...was thought to be tighter by those making frequent use of interactivity', particularly for those new to using interactive whiteboards. Part of the planning process for both teachers was selecting resources in a discriminating way from the range of materials both commercially available and free on the Internet, neither had reached the stage of designing their own resources. The change in planning brought about by the technology available in her classroom is indicated by teacher A right at the end of her interview when she says that she '...may even stop writing lesson plans and things or brief notes and just go straight to putting it all on the computer....'.

To an extent, both teachers seemed to be in a 'transition' phase in another sense as well. Both used an ordinary whiteboard in the course of the lessons observed as well as the interactive whiteboard. It remains to be seen if this remains their practice in year's time, or whether this is a function affected by their choice of hardware and software, as different brands support text in alternative ways.

Both teachers also recognise that this technology is not a panacea, automatically leading to the involvement of all the pupils in the class. Their approaches are not identical but illustrate what may be two of a series of complementary approaches with this technology. Teacher A's emphasis is on the involvement of pupils in the lesson and in providing variety of experience, whilst teacher B has a greater concern with clarity of resources and with a multi-sensory approach to learning.

A less positive note emerging from the case studies was that both teachers had difficulty distinguishing between the use of just a data projector and the use of a data projector in conjunction with an interactive whiteboard. This was evidenced both by their limited use of some of the functionality of the interactive whiteboard and in the interviews where some of their comments applied equally to a data projector on its own and to a data projector with an interactive whiteboard.

7.4 Discussion on study as a whole

This study suggests that there is some distance to go before we see really competent practitioners in using ICT to teach mathematics in more than a very few schools.

There is some suggestion from both the questionnaires and the case studies that teachers tend to use the same few functions, applications, software or similar that they feel confident with and are not necessarily exploring the full potential of the technology. This can be seen, for example, in the case studies where both teachers gave no evidence of using the 'restore annotation' function, the SMART keyboard, and were not necessarily always using the full potential of the interactivity as distinct from projecting the image onto a non-interactive screen.

BECTa (2002c) provide a useful table discriminating between departments described as 'emerging' and those described as ' advanced' in their development of their use of ICT in teaching and learning in mathematics. A key indicator differentiating between the two is that an 'advanced' department has a fully-integrated appreciation of the role and value of ICT. A number of the departments I surveyed could be described as enthusiastic 'emerging' departments in their use of ICT but few would really qualify as an 'advanced' department where there is equality of opportunity for all students in learning experiences with ICT. The two teachers in the case studies had access to sophisticated software and hardware in their classrooms and made frequent use of it, but seem yet to have reached the stage described by Detteri et al (1998) where discriminating use is made of a range of environments to link representations and to develop understanding of concepts.

It is encouraging that neither the survey nor the case studies suggest any inequality of experience between the two Key Stages.

7.5 Limitations to data collection and analysis

Consideration of the responses made by teachers to the questionnaire does identify some shortcomings with this instrument. Two teachers reported using an interactive whiteboard but not a data projector and two reported using an interactive whiteboard more often than a data projector. These are contradictory given that it is impossible to use an interactive whiteboard without a data projector. Therefore the item listing for a data projector on the questionnaire could have been more explicit. Had the items been distinguished by saying 'data projector (without an interactive whiteboard)' one could have been more sure that respondents were referring to using a data projector without an interactive whiteboard when giving scores for this item.

One key finding from the questionnaire was the generally similar use of all the resources (other than Logo) at both Key Stages 3 and 4. Given the reported equality of access by Key Stage, a further question of interest would be to find out whether there is equality of access according to pupil level of attainment (given classes are usually set by attainment).

Many teachers reported using the resources listed in a range of ways. What the questionnaire is not able to do is to explore some of these uses more fully, particularly where there are apparently anomalies. For example, some teachers reported using an interactive whiteboard for lesson preparation and ideas. Interactive whiteboards must be used connected to a computer where they form a type of interface where any mouse-driven software can be controlled by touching the screen instead of using the mouse or keyboard. They very often also come with their own presentation software. However, anything seen on the screen can also be seen on the computer monitor so there is no advantage to using the interactive whiteboard for lesson preparation. My assumption is that teachers reporting this use of an interactive whiteboard are actually referring to files, resources and materials produced either using the whiteboard presentation software, or other software packages, for use with the whiteboard.

Allocating comments made by the two teachers in the case studies to the twelve themes of Ruthven & Hennessy's model was quite difficult at times because some of the themes are closely linked. This linkage and overlap of themes is commented on by the authors, for example on p.71 where 'Routine Facilitated' is linked to 'Activity Effected' through the consideration of the effect of ICT on the pace of a lesson. The themes are also linked together by a co-incidence diagram on p.76.

It should be noted that Ruthven & Hennessy's themes came from the analysis of group interviews with seven departments so clearly the range of experiences will be far wider than for my study where I interviewed two individual teachers. It is not easy to find the differences between the interview schedule used by Ruthven & Hennessy and mine. Their paper simply says that participants were asked for examples of ICT use which they felt had been successful in supporting teaching and learning as a main prompt, and about what impact they thought ICT was having on teaching and learning in mathematics as a secondary prompt (p. 55)

8. Implications

The large-scale studies on the impact of ICT on attainment in mathematics as measured by national examination scores reported in the early part of this work leave one with an unsatisfactory conclusion that does not tally with other studies in mathematics education using different measures of achievement. Given this, it is necessary to look for other ways of exploring and explaining the relationship between ICT and the learning of mathematics. In part, the explanation for the lack of conclusive evidence from the literature in section 2.2 is that the situation is a complex one, involving all the key factors discussed in section 2.5.

This led me to the design of this study and to finding out teacher's views using a questionnaire with a defined sample, and to the two case studies which included observation of the teachers' practice. The findings of my study fit closely with those previously carried out in this field. I am left with an encouraging picture where the teachers surveyed are generally enthusiastic about the use and impact of ICT on their teaching. However, it is also clear that there is still much work to do before all teachers have the necessary skills, both in using the technology and pedagogically, for ICT to have a substantial impact on the learning of all pupils in secondary mathematics. Above all, we need to be using the enthusiasm many teachers have for the use of ICT in their teaching to develop practice.

There are a number of questions that still need to be researched and also issues that need to be resolved. It is important we find out why the kinds of large-scale impact studies referred to do not consistently report a positive impact of ICT on attainment in mathematics (Brodie, 2003). The issues to resolve here may be methodological with these studies, but they may also relate to the assessment process itself and differences between what is taught and what is measured by the tests. Brodie (2003, p. 3) also proposes an alternative explanation, suggesting that it is not ICT which brings the learning benefits but that it acts as a catalyst and enabler in the learning process. It is clear too, that there remains a very great deal of work to do with teachers both on confidence and competence with software and hardware, as well as developing their pedgagogies to incorporate effective use of ICT. Within initial teacher education there is the need to develop this pedagogy within new recruits to the profession, and perhaps to try to help them develop pedagogies that are less resistant to change than those of established teachers.

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Appendix A: Permission letter

Dear

I am writing ask for permission to observe ..... year .. lesson on ...... and to carry out a short interview afterwards with ..... I've discussed this with ..... and ..... is willing to take part.

This forms part of research I am currently carrying out on the impact of ICT on the teaching and learning of mathematics. The lesson observation is intended to inform and provide material for discussion in the interview. Data collected will not be used for any other purpose than this research and will be passed back to the school for checking and authorisation following the interview. It forms part of my research for a higher degree but may also be published in a suitable journal.

...... identified the mathematics department at Bay House as one of the very few we work with where there was a high use and impact of ICT in mathematics and I am interested in exploring this further with her in this way. I hope you will be willing to allow ...... to participate.

Yours sincerely

Rosalyn Hyde
Course Tutor, Secondary Mathematics PGCE

Appendix B: First trial questionnaire

Impact of ICT on mathematics teaching and learning survey

The aim of this part of my study is to investigate the use of those software packages/peripherals/hardware that have most impact on mathematics learning, not just those that are used most frequently. Some resources might be used infrequently, but could help pupils with a specific aspect of the subject that they might otherwise find difficult.

Q1

a. Please list below the main software packages (including websites, CD ROMS, specialist peripherals and communications software) that you use in the teaching of mathematics.
b. Please rate each package in terms of its frequency of use on a scale of 1 - 3 where 1 = annually (e.g. within a specific topic), 2 = regularly (e.g. most terms), 3 = often (e.g. most weeks).
c. Please rate each package for its impact upon pupils' learning in mathematics on a scale of 1 – 4 where 1= very little, 2 = some, 3= significant and 4 = substantial. For websites, please also give an overall rating.

Software packages (including CD ROMs)
(title/description/publisher – please try to enter precise titles, for example Microsoft Word rather than office or word processing)

	Use	Impact
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		

Websites (include overall rating and then list sites worthy of specific mention)
Please include the URL
Overall rating

	Use	Impact
1.		
2.		
3.		
4.		
5.		

Specialist peripherals (e.g. digital camera, data-logging, graphical calculators)

	Use	Impact
1.		
2.		
3.		

Communications (e.g. email. Discussion groups)

	Use	Impact
1.		
2.		

Q2 How much impact do you feel ICT has had on pupils' learning at each key stage?

	Very little	Some	Significant	Substantial
Key Stage 3				
Key Stage 4				

Q3 Do you use ICT to support interactive whole–class teaching?
If yes, please list the main resources which you use to support whole-class teaching:

Software	Use	Impact
1.		
2.		
3.		

Hardware (e.g. Interactive whiteboard, Plasmaboard, Projector, large screen monitor)	Use	Impact
1.		
2.		
3.		

Q4 Please use the space below to make any comments that you feel are relevant to the contribution made by the use of ICT to pupils' learning.

Appendix C: Second trial questionnaire

Impact of ICT on mathematics teaching and learning survey

The aim of this part of my study is to investigate the use of those software packages/peripherals/hardware that have most impact on mathematics learning, not just those that are used most frequently. Some resources might be used infrequently, but could help pupils with a specific aspect of the subject that they might otherwise find difficult.

d. Please list below the main software packages (including websites, CD ROMS, specialist peripherals, graphical calculators and communications software) and hardware (for whole class teaching) that you use in the teaching of mathematics.
e. Please rate each package in terms of its frequency of use on a scale of 1 - 3 where 1 = annually (e.g. within a specific topic), 2 = regularly (e.g. most terms), 3 = often (e.g. most weeks).
f. Please rate each package for its impact upon pupils' learning in mathematics on a scale of 1 – 4 where 1= very little, 2 = some, 3= significant and 4 = substantial.
g. For each item please indicate the uses to which you put the resource in supporting the teaching and learning of mathematics. You may tick more than one box.

			Use made of the resource			
Item	Frequency of Use	Impact	Whole class teaching	Pupil use	Lesson prep. and ideas	Other - please specify
e.g. Web sites						

How much impact do you feel ICT has had on pupils' learning at each Key Stage?

	Very little	Some	Significant	Substantial
Key Stage 3				
Key Stage 4				

Q4 Please use the back of the sheet either to continue or to make any comments that you feel are relevant to the contribution made by the use of ICT to pupils' learning.

Appendix D: Final questionnaire

Name:.................................
School:.................................

Impact of ICT on mathematics teaching and learning survey

The aim of this study is to investigate the use of those software packages/peripherals/hardware that have the most positive impact on mathematics learning, not just those that are used most frequently. Some resources might be used infrequently, but could help pupils with a specific aspect of the subject that they might otherwise find difficult.

a. Please list below the main software packages (including websites, CD ROMS, specialist peripherals, graphical calculators, and communications software) and hardware (for whole class teaching) that you use in the teaching of mathematics. A list has been started for you, please add any additional items on the blank lines.
b. Please ring a number to rate each package in terms of its frequency of use on a scale of 1 - 4 where 1 = annually and 4 = most lessons.
c. Please ring a number to rate each package for its positive impact and benefits upon pupils' learning in mathematics on a scale of 1 – 4 where 1= very little and 4 = substantial.
d. For each item please indicate the uses to which you put the resource in supporting the teaching and learning of mathematics and indicate which Key Stage you use it in. You may ring both and you may also leave some columns blank.

	Frequency of use Annually			most lessons	Impact Very little			substantial	Use made of the resource: Whole class teaching		Pupils use		Lesson preparation and ideas		Other, please specify	
Web sites	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
CD ROMS	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
Graphical calculators	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
Interactive whiteboard	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
Data projector	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
Word Processor	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
Spreadsheet	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
Dynamic Geometry software	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
Graphing package	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
LOGO	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
PowerPoint	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4
	1	2	3	4	1	2	3	4	KS3	KS4	KS3	KS4	KS3	KS4	KS3	KS4

How much positive impact do you feel ICT has had on pupils' learning at each Key Stage in mathematics at your school?

	Very little	Some	Significant	Substantial
Key Stage 3				
Key Stage 4				

Please use the back of the sheet either to continue or to make any comments that you feel are relevant to the contribution made by the use of ICT to pupils' learning in mathematics.

Please return to: Ros Hyde. Research and Graduate School of Education, University of Southampton. Highfield, Southampton, SO17 1BJ by 31st May.

Appendix E: Data collection tools

Lesson observation

1. Write a summary description covering:
2. What did the teacher do?
3. What did the pupils do?
4. What ICT was used?
5. How was it used?

Try to capture some phrases verbatim.

Semi-structured interview

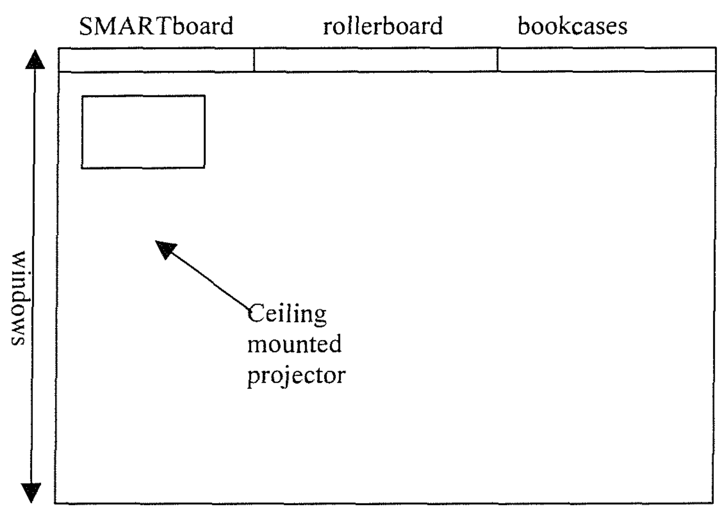
1. How did you choose whether or not to use ICT today?
2. How do you choose whether or not to use ICT in a lesson? Please give some examples.
3. What did using ICT add to your lesson today?
4. What does ICT add to your lessons? Please give some examples.
5. Why did you use ICT today?
6. Why do you use ICT in your teaching? Please give some examples.
7. What would have been different about your lesson today if you hadn't used ICT?
8. What would be different about your lessons if you didn't use ICT? Please give some examples.
9. How did ICT help your pupils learn mathematics today?
10. How does ICT help your pupils learn mathematics? Please give some examples.

Appendix F: Case study data

Case Study A

Introduction

A is a teacher at a large 11-18 secondary school in a town on the South Coast. She has responsibility for ICT in the department and is the school-based mentor for trainees. The mathematics department moved into their brand new teaching block six months before which contains two ICT suites, one of which is for dedicated use within the mathematics department. Her classroom is the only one in the department with an interactive electronic whiteboard (SMARTboard). The classroom is wider than it is long with a roller whiteboard in the centre and the electronic whiteboard to one side. A small portion of the windows down one side can be covered by a blind to improve visibility. There is a ceiling mounted data projector and the teacher had a laptop. The class is a top set year 8.



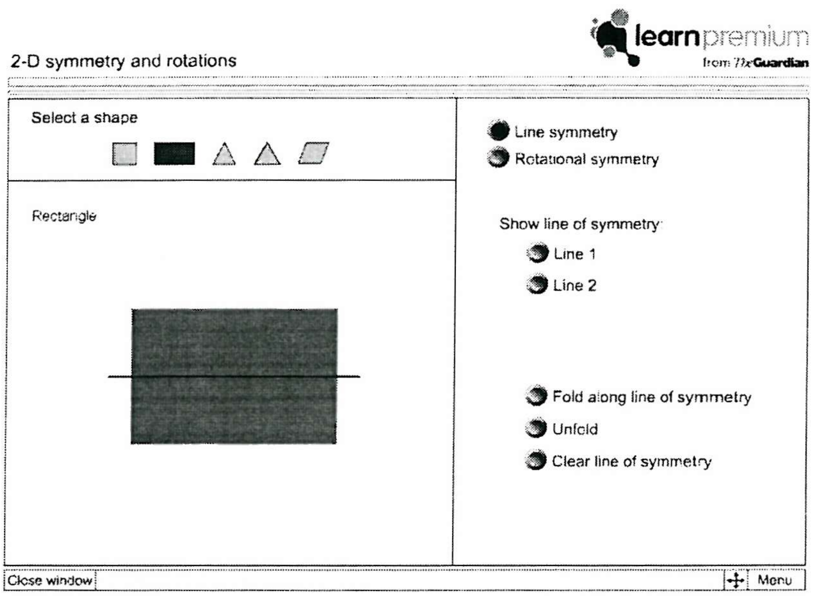
Description of lesson

The classroom is dark, but it is still too light for the projector.
As the pupils arrive 'Countdown' is ready on the roller whiteboard and pupils start working on the task.
The SMARTboard is displaying the title 'transformations' on a page of the flipchart software that comes with the board.
Pupils are contributing suggestions as to the solution of the Countdown problem.
The lights in the classroom go off so that the teacher can use the SMARTboard.

The teacher asks the class: 'What kinds of transformation are there?' She uses the SMARTboard pen to record pupil contributions:

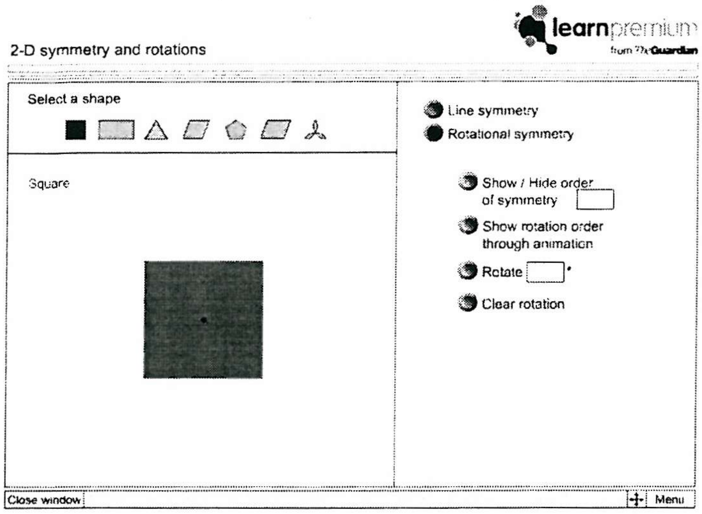
-reflections
-rotations
-enlargement
-translations
-tessellations

Tessellations is suggested early by a pupil and, although it is not what the teacher is looking for, she acknowledges it by leaving a gap and writing it further down the board.
The teacher asks: 'Give me some words related to reflection'
All the files needed for the lesson are open along the toolbar on the screen.
The teacher changes the screen to a preloaded page from a subscription web service:



The page allows the user to select a shape, which is displayed underneath. The page then allows the user to select from the range of actions shown on the left.
The teacher demonstrates folding and unfolding along the line of symmetry with the chosen shape.
The pupils clearly liked the folding and unfolding animation as mutters of 'do it again' could be heard.
The use of the web resource allowed the teacher to focus on the classroom questions and to stand and face the class whilst teaching.
The teacher generally operates the SMARTboard using her finger.

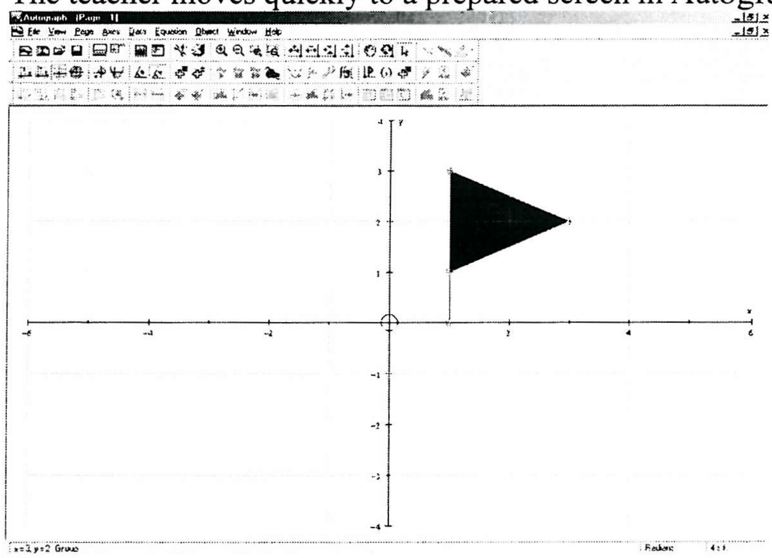
The teacher changes to the reflection option on the web page:



Pupils are again able to see the animation of the rotation. They are clearly engaged – lively and chatting about the task.
Teacher returned to the flipchart software to a prepared slide:

> Reflections
> To fully identify a reflection you need to know:
> The line of reflection or mirror line (normally identified with a dotted line)

The teacher moves quickly to a prepared screen in Autograph:



The teachers says: 'We are going to reflect the shape'
Two pupils put their hands up in order to respond immediately. The teacher follows this line of enquiry by allowing one of them to come up to the board and draw on the reflection using a SMARTboard pen.
The teacher then asks the class what assumption the pupil has made as to where the line of symmetry is by asking: 'What's the equation of his line of

symmetry?'
The software is then used to check that the reflection drawn is correct.
Pupils are keen to draw on the board.
The teacher says that they are going to draw the reflection in the x axis and does so using the software.
Some issues are raised at this point about how easy pupils find it to use the SMARTboard. 'You can't see it up there', 'No you can't'.
Pupils are asked for the reflection in the line $y = x$. One comes up and draws it incorrectly on the board. (He draws the rotation 180° about the origin).
The teacher operates the computer using the laptop at this point to draw on $y = x$ as the mirror line (presumably because it is easier than using the SMARTboard for this).
Pupils tend to stand in front of the screen. 'I can't see'.
Pupils start to struggle at this point so the teacher asks them to do the task in their maths books. The teacher says: 'Copy the grid into your books, copy the flag, copy the line of symmetry and reflect it please'.
The coordinates of the points of the flag are given on the roller whiteboard.
The sun has now come out so pupils can see to write in their books.
The teacher swaps to using the roller whiteboard to demonstrate how to draw the reflection, She goes through the example on the whiteboard with pupils coming up to contribute.
She then reverts to using the SMARTboard to show the solution using the software.
She sets the pupils some bookwork and changes the SMARTboard to show the previous slide from the flipchart.
The sun goes in and the teacher switches the lights on.
The teacher seems confident in swapping between the two boards.
The SMARTboard flipchart has four slides prepared but only two are used.
The class are brought back together. As a plenary they are asked to contribute key words from the lesson which are written up on the roller whiteboard by the teacher.
The pupils are then told that there are two things to finish off now. They return to the Countdown activity but there is still no correct answer.
The teacher then launches the Equivalent Pairs software from SMILE using her laptop.
The class are enthusiastic about playing boys versus girls and there are cries of 'yes, yes'. One girl and boy begin to play the game where they have to look for matching pairs of fractions.
Pupils are clearly excited by this and contribute suggestions for their team.
The girl does well in standing out of the where, but from where I was sitting the boy tended to obscure the board.
Lessons here are 1 hr and 10 mins so this was an additional activity at the end of the lesson.
Teams are trying to distract one another.
Pupils have to decide whether or not the pair of fractions match – if they make an incorrect decision the software demonstrates visually why they are wrong.
The lesson finishes with two more pupils playing the game.

Interview

1. How did you choose whether or not to use ICT today?

It all depends on the subject you're teaching. Transformations is quite visual so it obviously suits the whiteboard a lot easier. It's quicker to get a graph up and get sketches, put a shape up there and reflect it or rotate it whereas on a whiteboard it takes a little bit longer and you have your back turned to the class for longer. It gives you more time to interact with the class and they can come up and draw on.

2. How do you choose whether or not to use ICT in a lesson? Please give some examples.

Something like statistics recently with year 7 we did a class survey up on the board we had Excel up the children got quite involved in seeing the data go up and then comparing as it was going saying who's taller who's shorter. It's good for starter activities, it's good for plenary sessions. It's good for putting up 3D shapes and 3D sketches You can use it for anything. The more I use it the more I get into it ....and its just practice and being familiar with the software and getting it to do what you want it to do. With the SMARTboard software you can prepare lessons in advance.

3. Are there topics you haven't got so used to using it with?

Only been using it for 6 months or so. Writing straight on to there – sometimes I do and sometimes I don't. Handwriting doesn't come out particularly well on the board. If there's a lot of writing to do I'll go back to the normal board unless I'm ultra prepared and I've typed it in in advance. I can't think of any topics I'd say no, I'd definitely not use it for.

4. What did using ICT add to your lesson today?

It gives it more impact. It brings it home. It's just a different way. It brings it alive for them. They had the opportunity to see the paper folding today when we were looking at the symmetry and the shape rotating. Things you often want to do on a normal whiteboard but you can't – you'd have to have the shape cut out and stick it up. Gave you the flexibility to actually bring it alive for them.

5. When you say more impact, do you mean more visual impact…?

Yes

6. More involvement by the pupils?

Yes that's right. With the equivalent pairs we had at the end we children coming up writing on the board actually getting involved in the lesson. They like that, they like watching, coming up and writing on the board. They hold it against you if they haven't been chosen to come up and use the whiteboard. One of them jokes at me continuously that she hasn't been chosen to use the whiteboard. Everyone in the class likes to be involved in it. It just makes the lesson much more pupil involved.

7. We talked a little bit briefly earlier about pace. In what ways do you think that using the ICT increases the pace for you?

Because it enables you to quite quickly flip between different packages which gives you more impact, so I can go very quickly between using line symmetry using an Internet resource to going to reflections on Autograph without having to stop the lesson, right you've got to draw out the grid, you've got to draw out the thing, all without spending hours beforehand getting it all up on the board. You can only go round the board a few times and on occasion go round it more than that.

8. I was quite interested in how you were positioned, how you were standing. Because you had the board you were always facing the class and interacting with them and that to me looked quite significant.

Yes, ideally the whiteboard shouldn't be there (gesturing to the SMARTboard). It should be in the centre (gesturing to roller whiteboard) because obviously that would give more flexibility. When we first came in there was a complete table alongside there (gesturing to the corner in front of the SMARTboard) and I had to ask for it to be moved as I ended up sitting on the table to get out of the way of it because you need the flexibility to be able to stand on both sides depending on what you're doing and where you want to get to. You learn quite quickly how to position yourself so you can see the class all of the time and don't blind yourself with the projector. It is nice to be able to keep on an eye on the class a lot more of the time although you just have to be careful you don't go too fast because I seem to be stood around for a long time and you think 'surely they've finished by now, sure they've written…' and they haven't and you have to be very careful not to go on too quickly for them.

9. They haven't the got the time maybe to write while you're writing the next bit

Yes

10. Yet you're all ready and prepared to move on aren't you

Whereas they're thinking, processing it and write it at the same time and the understand as well.

11. Are there other examples you can give me about ICT either adding those things or other things to your lessons?

Like what exactly?

12. Well you talked about year 7 using Excel, a little about having their whole data collection up and they were all ready to start comparing the data as it went up as they've got instant access to it so ..

One of the things we have been doing recently with our year 10s we've basically tried to put the year 10 statistics coursework ICT based so they've been upstairs using the computer suite but what the interactive whiteboard has been useful for is that teachers have come in beforehand and they've been able to talk pupils through the kinds of things they might want to do. So they've been able to talk through on Excel how they go about collecting their data, how they use their random numbers, then switch in to Autograph to look at how you go about drawing scattergraphs, how you go on to doing box plots and things like that. So it's been excellent for doing that because you talk to the whole about it without them having the distraction of having the computers then in front of to get distracted by. We go through the process of doing it and then being able think about how they are going to focus their own aims…So its been useful for the year 10s coursework. We're just starting to find out its full impact and we can start to use it for anything. I've done lots on it. Quite a lot of people have said 'Can I come and see' so I've done lots of little demonstration lessons along the way. It's very good for having there...bring up past lessons on it. The icecream scoops for example I had some of the things that we did, last lesson we looked at this, we did this, you've got to make sure you've got your introduction there, your method, your table of results, it's very good for bringing up past lessons. One other thing I have done is I've taught a cover lesson for a teacher who was off sick in here, saved the lesson on the SMARTboard and was able to print in out. Obviously it's excellent for them because they can see exactly what you've done and what the pupils have seen.

13. Do pupils ever ask you to go back a slide?

Yes, quite often. 'Oh you've gone a bit fast there can you just go back to the previous one?'. Which is good. It's always there, so they can refer back to it if I've gone too fast or they haven't quite caught up.

14. What do you think would have been different about your lesson today if you hadn't used ICT?

It would have had had less impact on children. I think they would have ended up doing a lot more by hand and we'd have spent more time reviewing stuff that they should know. Being a top set I didn't want to spend an awful lot of time looking at line symmetry or rotation symmetry, because it's prior knowledge, worth a recap just to remind them of the key words. But apart from that, not much. That would have taken longer to do had we not had the interactive whiteboard up there, we would have probably ended up doing a lot more with them doing it rather than watching the whiteboard, we'd have gone back to more traditional 'open book at page and get on with it'.

15. One thing we haven't talked about in terms of you using ICT is graphing. Do you use Autograph?

Across the school we use Autograph we use both for the stats pages and the graphing pages. With my top set year 8 again, we've done a lesson on graphing looking at the impact of what happens with $y = x$ when you change the gradient and what about the intercept? That works quite well.

16. What do you think it is that ICT allows you to do with that kind of activity that you wouldn't get on paper?

If you are doing it on paper, if you are trying to get them to draw $y = x$, $y = 2x$, $y = 3x$,...they get bored by the time they've got to $y = x$ whereas on the computer it allows them to very quickly see what the difference is. They don't have to think about how they go about plotting it. You are looking things like what the gradient is....what's happening that you are interested in. Not whether or not they can draw the graph that goes with it so you're saving yourself an awful lot of time. And you can you can quickly get across the impression that it's the gradient that changes, as that gets bigger the gradient gets steeper and as it gets negative it goes the other way so you've got the facility there to get across the point without having them to plug through all the graphing which they find quite .....

17. Do you have any instances of pupils extending that kind of question further because they've got the facility of the ICT? Is that something potentially they could do?

Yes, they've got the potential there, I think quite a few of them have gone further than they would have done had they had to do it by hand. Especially the girls spend so long getting everything neat and tidy they quite often get behind because the boys will rush on they are quite happy with a quick cross but the girls want it all very neat and that obviously slows them down. So they don't quite learn as much maths as they possibly could have done so I think that way they are actually extending themselves further. But I've had like one of the boys who is, I've got quite a few in here who need extending, they can very quickly go on to looking at quadratics and things like that and extending themselves that way, they get quite interested in looking at what happens with a cubic as well. They'd get bogged down in the paraphernalia of sketching it by hand whereas the computer it's all very quick and they can grasp it very quickly. There's nothing particularly difficult about looking at the shapes these curves have, it's the drawing behind them and understanding how....

18. You talked about upstairs in your computer room you are able to override and have the teacher screen on all the pupils' screens. Can you give me any examples of you having used that facility?

It's very good, if you need to call everyone together and talk over a particular thing that's going wrong, you can basically capture their entire screens and make them turn to the front so they can't do anything while you've got it. So that's one very good advantage of it. You can also give a demonstration via teacher-op. We've done that with the stats coursework, this is what you'll do, you're going to do this and then... They can basically see what's happening on your computer on theirs. You can also target individual computers, it's got a facility to allow you to, it will basically every ten seconds it will update what's happening on each computer so you can catch people doing things that they shouldn't be. At which point you can just take control of their computer and tell them to stop doing that. You've also got the facility to send them a quick message so like 'get off the Internet' or that sort of thing. They're like 'oh, wow, OK!' it's just a very good way of ensuring they are doing what they should be doing. We are always on the Internet up there. We have caught them doing all sorts of things.

19. How do you think your use of ICT today helped your pupils learn mathematics?

It brings it alive for them. It gives them another way of looking at it. They quite often get bogged down in detail and they don't like to do certain things whereas doing it on the computer brings up the pace, more impact, so they can see these things appearing in front of their eyes without them having to sit and draw it. It gives them another way of looking at things and quite often when we use the Internet resources that are out there it brings in real-life examples as well, you can see where its used in real life. Something else I've just done recently we did equations and there's a very nice Internet resource that looks at equations. It looks at how you add or subtract things to both sides it does that and that brings that very much alive. You've got something like $9x = 2x - 25$ you take 25 from both sides you can actually take 25 from both sides and they can see the equation getting more complicated without them having to actually go through and make the mistakes and putting the computer to do it correctly so they can see what their mistakes will actually lead to. I think they just appreciate not having an entire lesson writing and doing exercises. It's nice to start a lesson doing something on there and then have a complete change to what the main lesson is, or to end it like the lesson we did today which was on transformations but finishing activity was on equivalent pairs. Lessons are one hour and ten minutes here, which means you need to divide it up into different sections especially for the middle to lower ability they lose interest and it all becomes very hard. If you can very much go to something on the board. One of the things we do for numeracy is to use the BBC Skillwise website which is very good for my low ability GCSE groups and they've just times tables tests on there and they have a times table grid you basically just have to click the right number. We'll say what is seven times four so they have to find twentyeight on there. There's like a hundred questions there and it will keep the group going for a good ten, fifteen minutes. Whereas if I did times tables tests with them they'd be bored and just having a different resource to use or different way of practicing key skills is good.

20. Do you think there are aspects of novelty that might wear off?

No. I think this is something that will keep going because ... I haven't found the novelty's worn off yet and we've been here six months and still they want to have a go at certain games and they like the competitive aspects of it. They like doing girls versus boys and sometimes they like even to gang up on certain people...I've had to stop that now. Obviously because we have the classes for a year there's going to be a new novelty value, new classes coming in. Perhaps if everyone in the school had them then possibly it might start to wear off. At the moment where it is a rare resource it's always going to have impact. I think it always will have impact, regardless of whether or not there is one in every class because it's just bringing things alive. Rather than doing a lesson and saying 'What happens here if you fold the piece of paper over' you can see it. As we progress there's going to become more and more activities designed for the whiteboard. I've seen the amount of paperwork that comes through to say 'buy this for your whiteboard' at the moment to get the idea of things that are going to be coming out. Hopefully they will continue to change as we get more and more of these things in the classroom.

21. One of the other key aspects of pupils using ICT is getting instant feedback so you haven't mentioned that specifically, but I'm guessing that that's something you've seen in quite a number of activities.

It's nice. On SMILE you've got things like RHINO and so on. That's good in that they like to know whether or not they're in the right place and get the feedback that way. They do like to...especially if they can play a game against the computer or whatever they like to be able to beat the computer. So in that way yes getting feedback is good. Things like the learn premium programmes they can get instant feedback on questions on there.... So yes it's always an advantage if you can give feedback to pupils as soon as possible if you have the facility to do that.

22. Which do you think has had most impact on your pupils' teaching and learning, the projector on its own, a projector and a SMARTboard or a computer suite?

It's difficult because they all came at the same time. The computer suite is great. I don't use it as often as other members of the department because I have this facility in here which we obviously need to make sure is used to its full effect. Probably for my pupils if you said to them what's had the greatest impact they'd say the whiteboard because they've been exposed to that more often but they still like the ability to go up to the computer room and go in that as well. It's a difficult one to say.

23. Do you think they serve different purposes?

Yes.

> I'm quite interested in.... the way that the pupils came up and used the SMARTboard it's much more teacher directed it's in a sense like the teacher using ICT. If you only had that that's about the teacher using ICT largely, whereas the computer suite is about the pupils using ICT.

That's the difference basically. If I want them to go on do something then we go up to the computer room whereas if I want to demonstrate, or show them something with a bit more impact I'll just use the whiteboard. Because obviously you can get some of them involved but I'd be hard pushed to get every single one of them up and involved in one maths lesson. Definitely it's more hands on for me using that and hands on for them using the computer room.

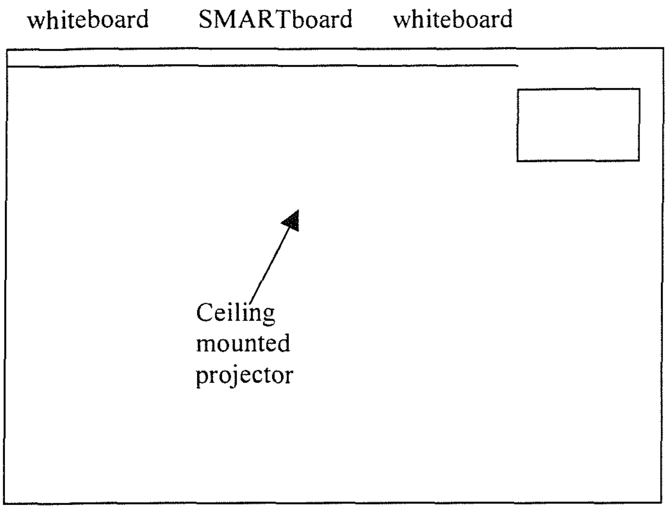
24. How significant do you think are aspects of being able to pre-prepare?

For me, because I'm fairly computer literate anyway, I'm happy typing in, I'm happy working with the computer, so for me it's huge, I can quite happily sit and set up a lesson. Quite often, perhaps I'll try and do it more next year, I may even stop writing lesson plans and things or brief notes and just go straight to putting it all on the computer and doing it via the computer rather than having paper records. Because sometimes, when I'm writing up my lesson plans thinking about.... I can just as easily have it typed into the screen and have it there ready for the lesson. That would be the advantage for me, whereas for other people who aren't quite so computer-literate I don't think it would have quite so much impact.

Case Study B

Introduction

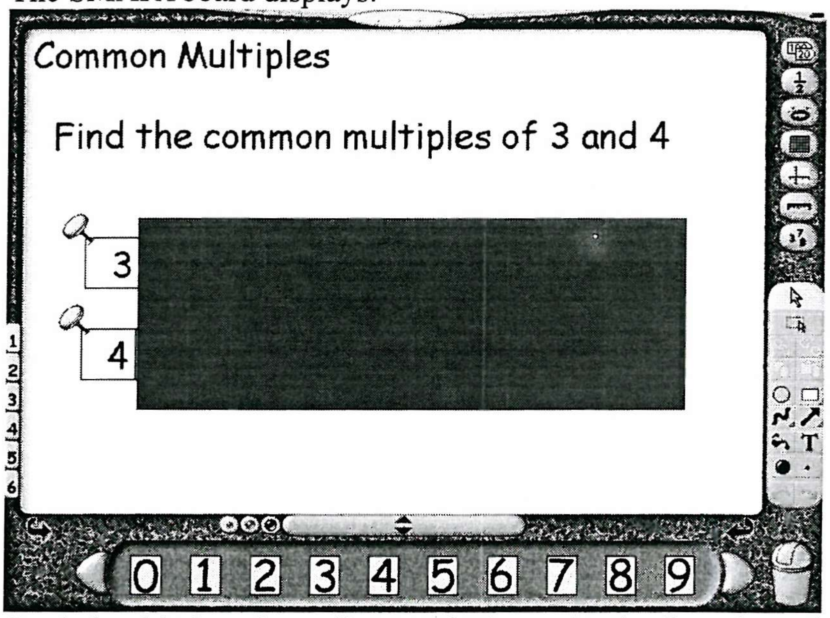
B is a teacher at an 11-16 girls' school in a city on the South Coast. She is the school-based mentor for trainees and has taught at the school for several years. The mathematics department is based in what she refers to as 'huts' but are temporary classrooms that have clearly been on site for sometime. Last year the school equipped six of these with interactive whiteboards and data projectors as well as a single networked computer. At the same time they bought the 'Mathsalive' scheme from Research Machines for Key Stage Three. They also have access to the school's computer suite. The classroom has the SMARTboard mounted in the middle with ordinary whiteboard space either side and a ceiling mounted projector. The class is a middle to lower ability year 7.



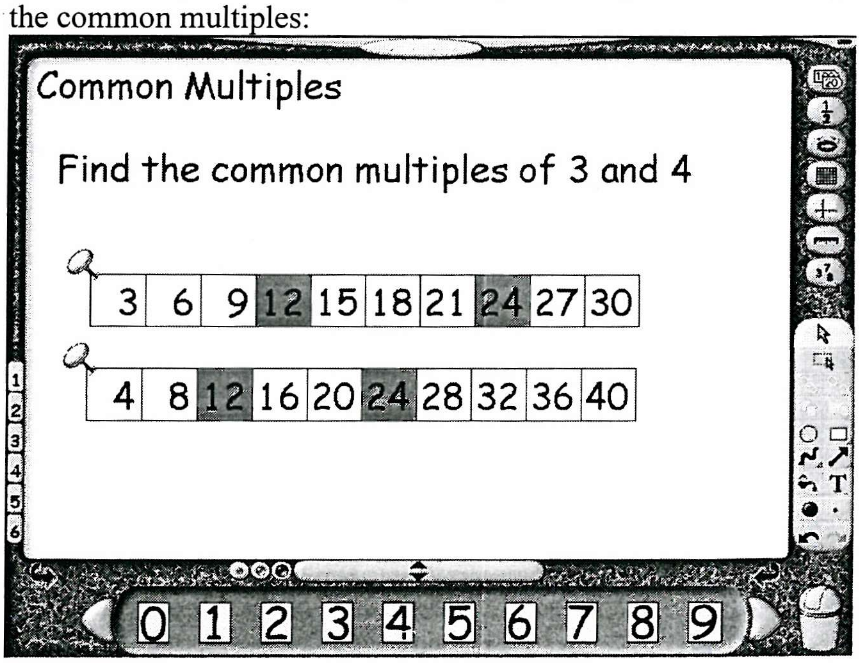
Description of lesson

The lesson starts with the teacher giving out the holiday homework which she had written on the right hand whiteboard before the lesson began.
Pupils are given a table square to assist with the homework.
The date and title are already written on the left hand board.
During this start to the lesson pupils are given a mini whiteboard, pen and cloth.
The teacher asks the pupils to write on their boards 'any multiple of three that comes in your head'
Next they are asked to: 'show me your board'
Then to write 'any multiple of seven' and show her
The teacher turns on the data projector whilst this is going on.
Next they are asked to: 'Write the first six multiples of eight'
She turns off the first row of classroom lights.
And next pupils write and display the first six multiples of thirteen. They are encouraged to think about how they will work out the multiples of thirteen.
When pupils display their boards, the teacher checks them visually and gives some pupils specific feedback as to their work.
The teacher loads the 'Easiteach' presentation 'Common Multiples' from Mathsalive.
She asks them to split their board into three horizontally and demonstrates how to do so on the left hand whiteboard.

The SMARTboard displays:



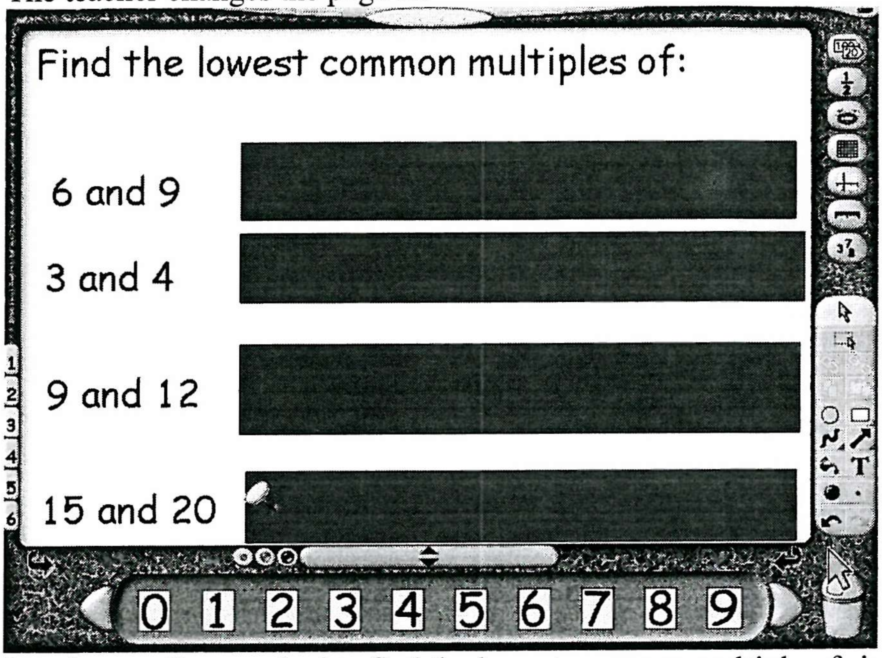
On their whiteboards pupils are asked to write the first six multiples of three in the first row and then the first six multiples of four in the second row. They then have to circle any multiples they have in common; any that appear in the multiples of three and the multiples of four.
The teacher says: 'Show me your board when you've circled the ones they have in common'.
Next their attention is focussed on the SMARTboard. The teacher tries to pick up the blue rectangle with her finger to drag it back. This proves impossible. She says; 'It worked this morning'.
A pupil is heard to say: 'Miss, do you know how to work it?'.
The teacher closes the software and reloads it from the Mathsalive management system. *The problem appears to me to have been that the wrong tool was selected on the tool bar.*
Now she drags he blue rectangle away to the right with her finger to show the common multiples:



The teacher asks: 'What's the lowest common multiple of three and four?' Pupils offer solutions and are prompted to consider the wording of the question in order to find the answer.

Pupils then copy from the left hand whiteboard and write on the third row of their whiteboards 'the lowest common multiple of 3 and 4 is 12'.

The teacher changes the page to:



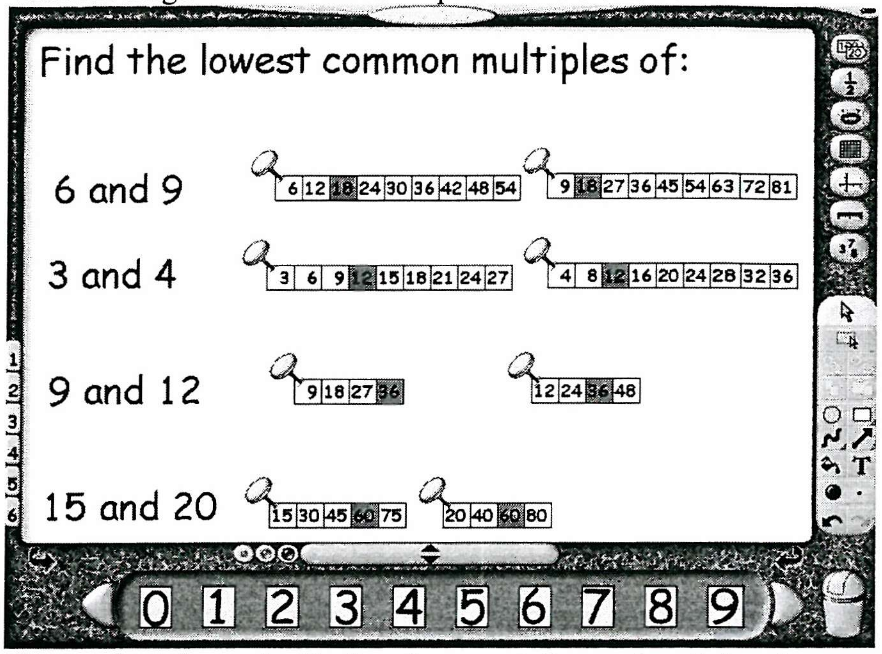
In pairs, pupils are asked to find the lowest common multiple of six and nine. They split their mini whiteboards into four, as shown on the left hand whiteboard. The pupils are asked to write their answer in the top left hand box.

The teacher circulates as the pupils work in pairs, doing the activity on the SMARTboard.

The teacher hands out the worksheet for the next activity whilst pupils complete the current activity.

Pupils are then asked to show their mini whiteboards.

The teacher goes through the questions and drags the blue rectangles aside with her finger to show the multiples and the solutions:



The teacher closes the Easiteach presentation and switches to a pre-loaded Word file on the task bar. She shows them an exercise from Mathsalive.
Pupils do the exercise, writing the answers on the sheet they have been given and reading the questions off the SMARTboard.
The teacher does the first question together with the class.
Some pupils are clearly using the multiplication grid they have to help them.
Pupils contribute to the joint effort of doing the first question.
Pupils then work on the rest of the questions independently, putting up their hands up if they need help. They are told that they may use the table square if they wish.
They are also told that they can use colour to show up the common multiples if they wish.
Several times during the lesson the screensaver activities – once when the pupils are doing the individual work from the board.
Pupils work on the activity for a few minutes and then the answers are checked. Pupils contribute answers.
Unfortunately, there is no time for the planned 'Haunted House' game in the lesson plan. This is because the lesson started late because the assembly previous to it over-ran.

Interview

1. How did you choose whether or not to use ICT today?

Well, partly because I knew you were coming I definitely did want to use a little bit of ICT. I knew you were going to be looking for that. The game I had planned to use at the end was revising on the topic which was really factors and multiples and primes. I thought it was nice and clear, the layout was nice and clear showing how to find multiples of different numbers and the fact they'd used colour to highlight the common multiples. I liked that. I abandoned the following boards, there were two further boards that I didn't use, because they looked far too complicated for my class, they didn't look as clear.

2. How, generally, do you choose whether or not to use ICT in a lesson? Can you give me any other examples?

The planning takes quite a long time. So provided I've had time to do the proper planning the week before then I will use it. Another example, there's lovely questions on probability that you can use where it shows different coloured beads in a jar. It's just lovely and simple. It saves you having to actually have the beads in jars as well. You have them up on the screen. It's clear for the pupils and they like coming up and having a go as well, moving things around and changing the probabilities.

3. What do you think using ICT added to your lesson today?

It saved me from having to turn my back on the class and write on the board all the time. I think it was very clearly written and there could be no doubt about what a number was or which numbers were being highlighted. I think in general, pupils do like to look at the interactive whiteboard but they also do like their mini-whiteboards that they used today. So there was a little bit of reluctance to not look at the mini-whiteboard and look at the interactive whiteboard from them.

4. The two strategies I thought went very well together because you knew they'd participated, they all fed back and it involved all of them

We learnt very early on that we had to do that. When we first started you'd have one or two who felt very confident with computers wanting to come up to the front and the others would have a nice relax and sit back, fold their arms and not bother doing very much so we figured that out pretty quick and made sure we'd invested in the pens which you can see I used those pens just earlier this week actually with those girls and I think I needed three new pens then and I then today it would be about four new pens. So it is expensive really.

5. You've talked particularly about using the Mathsalive resources and using the interactive whiteboard. What other kinds of things do you use ICT for?

We have through Mathsalive activities like Geometer's Sketchpad and with Geometer's Sketchpad you can plot functions so it's quite nice, straightforward, for showing the different shapes of graphs, linear, quadratic. That's much less costly taking them into the computer room than using our set of graphics calculators which have been battery-less for about a year, we've finally managed to get funding for more batteries but Geometer's Sketchpad is very useful for them. The old traditional things like LOGO that pupils are involved in using, there's some nice tessellation work, too. Proof of Pythagoras' Theorem is on a web site that we've looked at and shared between the department. Very nice. So if someone finds something they tell the others and post it up onto our shared area.

6. So you actually got the license for Geometer's Sketchpad through Mathsalive but you use it independently in its own right as a piece of software with other classes…

That's right, yes we do.

7. Do you use it or do the pupils use it hands on as well in the computer suite?

Tend to show them towards the end of a lesson how to use the package and then give them a worksheet work through basically when we go into the computer room.

8. What is it do you think that those kinds of activities add to your teaching?

I think it speeds it up. So, for example with graph drawing it can be so tedious to plot the points, so slow to plot the points, and it's really just understanding the shapes of the graph, to change things very quickly, and because the pupils can change things very quickly they stay interested I think they become a bit bored if activities take too long to do. They tend to go 'oh' if you're plotting graphs in class whereas if you're plotting them in the computer room they enjoy it and I think they get further, they learn more.

9. Have you used Geometer's Sketchpad with pupils for doing constructions?

We haven't used it with pupils for that, no. We only started with Geometer's Sketchpad this year. I think that's something we should be looking into actually. I think we should be trying to develop that.

10. Is that a staff training issue then?

Yes, we do actually have another day when we have the RMAlive man coming in, or woman, coming in October and we've did say Geometer's Sketchpad we'd like further practice at that because we haven't really used it much in that respect.

11. How do you think ICT helped your pupils learn mathematics today?

They can learn just as much normally but I do think it just added to the clarity and with them seeing the colours on the board and being interested in what's up there I think that that aids memory because you've got the visual memory which is clearer when there's colours involved than if it's just boardwork. Also there's often bits of sound attached so you're aiding that sort of memory as well. And it's good for pupils often, didn't really do it today actually, but often, to read something out from the board which can help them to help remember it I suppose they did it with the worksheet today what lowest common multiple is rather than just see it or rely on someone else saying it it's good for them to say it themselves. We do do chanting as well at times, which is good for them I think. Helps with the memory. Today I think just really added to the clarity again saved me having to stand writing for a while on the board.

12. Are there other activities say perhaps particularly in mathsalive that you've used that illustrate those or other points about what ICT added to the lesson?

When you play the games in particular even if you only play them for a short period of time, perhaps five minutes at the end of the lesson if they've got through the rest of the lesson's work it does add to the excitement value. Playing 'Haunted House' they get very worked up as the ghost gets nearer, very keen to get the right answer, much more keen than they would be wanting the reward of a tick, the reward of getting through somewhere on a game they do enjoy. There's also a nice slalom skier to do with changing from mixed numbers to improper fractions and back again. It's quite difficult to make them really want to do fractions but they do from that so it definitely adds to the motivation.

13. So you particularly like some of the games and short activities...

Yes, short snippets and then if the pupils wish they can go and access the games themselves from the computer room. It's different games for years seven, year eight and year nine. For weaker pupils we give them the access codes for lower down as well and they're happy to use that. It's not called year seven it's just called G forty three so it's not too obvious.

14. What about some of the Easiteach presentations? Are there any of those you have particularly liked for a particular reason?

Easiteach is very good if you want to quickly draw up a grid, quickly draw up axes, scales as well, so decimal work, drawing scales. Again it's much clearer, much better, than me drawing it on the board. It takes a long time to scale correctly and evenly on a whiteboard. It needs to be done before the pupils come in really. Whereas with Easiteach you can just pull the scales out.

15. So do you develop some of your own Easiteach presentations as well as using..?

Yes, we all tend to save things ourselves as well that we've used and we have maths worksheets stored in the shared area as Number, Algebra, Shape, Space and Measures and Data Handling so we have a long list.

16. So you've been working on storing and sharing things.

Sometimes they're Easiteach sometimes they're just normal Word documents or spreadsheets, whatever. We all use the same list within the department and we've found that way if we can't find any materials it's very easy to go to other people's classrooms and ask them either for the sheets themselves or to try to look on the shared area and find them.

17. Do you use things like Excel with pupils?

Yes, we do. Number pattern work, we use that actually at the start of year eight. Just simple number pattern work, even drawing up times tables or drawing up different number grids. We use Excel too for the data handling work. I'm just thinking, I haven't actually done that this year, but in the past, we normally use Excel to feed into the bar charts and pie charts and so on. The pupils this year have had data handling projects lower down the school and it's been classroom based actually that's probably why thinking about it but if the pupils have wanted to add in use of IT they've been able to but they've been warned to label correctly etcetera.

18. Do you make as much use in Key Stage Four as you do in Key Stage Three?

At this present moment I'd say we tend to go for materials through the Internet so for example with the appearance of the box plot at GCSE we've found materials and then we have them to show to the pupils. The games as well, year seven, eight and nine, we do use at times with Key Stage Four to liven it up a bit because I think the work much heavier really at Key Stage Four than Key Stage Three. We are looking into, and I think we might have it for September, a scheme for Key Stage Four, and it's based on conceptual learning and going around, for example, what does it mean to have a mortgage, something like that, and using the maths involved to educate themselves in the wider world.

19. And that's an electronic based scheme is it?

It is, but it's brand new as far as we are aware. I haven't seen it yet. N, our head of maths went on a course and saw it there and was very impressed. So we're hoping it will....

Our head is very very keen for us to head for to try to aim for the maths specialist status and she is well aware that if she can put money into the use of IT in maths and funding for us when we need it really to try and help the pupils to progress its going to count in our favour.

20. You've just got this local training status. Are you a specialist college already?

No, so that must be a sub part of something.

Additional Notes

The previous lesson, which was the last in the day, had been spent in the computer room using 'Haunted House', 'Space Racer' (both games from Mathsalive) and a game from the BBC website.

In conversation, B said that the money for interactive whiteboards and projectors had made all the difference to the department because before that they had been frustrated. They had felt it was worthwhile buying both, and never considered buying projectors only, although she feels that it is the projector that is most important.

Appendix G: Questionnaire data

Websites

Full data set

	frequency	Impact
	2	1
	3	2
	2	2
	2	3
	2	2
	1	1
	1	2
	2	
	2	4
	2	2
	2	2
	2	2
	2	2
	1	1
	2	2
	3	3
	3	3
	1	2
	3	3
	2	3
	1	2
	3	4
	3	3
	3	3
	2	3
	3	3
	2	2
	1	1
	1	1
		1
	2	2
	2	3
	3	3
mean	2.0625	2.28125
s.d	0.7043392	0.83794
max	3	4
min	1	1

Amended

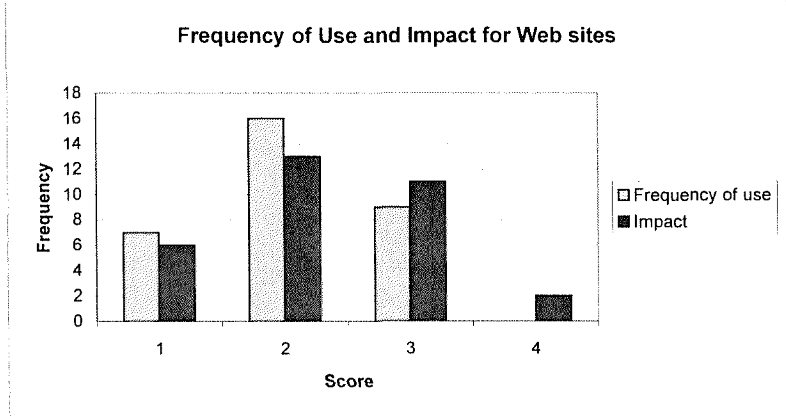
frequency	Impact
2	1
3	2
2	2
2	3
2	2
1	1
1	2
3	3
2	4
2	2
2	2
2	2
2	2
1	1
2	2
3	3
3	3
1	2
3	3
2	3
1	2
3	4
3	3
3	3
2	3
3	3
2	2
1	1
1	1
2	3
2	2

data with missing value pairs removed

Pearson's correlation coefficient
0.680414

Grouped data

	frequency	Impact
1	7	6
2	16	13
3	9	11
4	0	2
	32	32

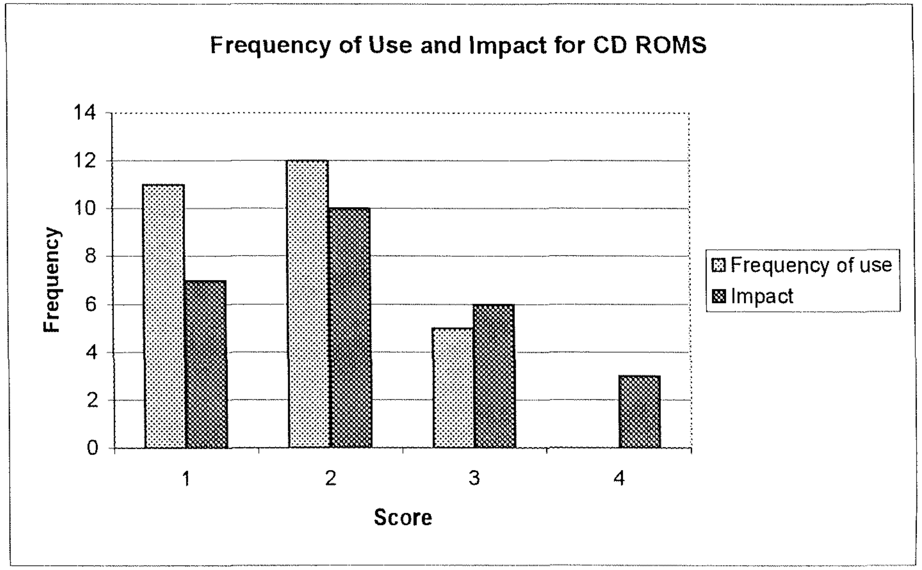


CD ROMS

	Full data set		Amended	
	frequency	Impact	frequency	Impact
	1	1	1	1
	2	3	2	3
	1	1	1	1
	1	2	1	2
	2		3	4
	2	3	2	3
	1	1	1	1
	2	2	2	2
	1	1	1	1
	1	1	1	1
	2	3	2	3
	3	3	3	3
	3	4	3	4
	2	2	2	2
	1	1	1	1
	3	4	3	4
	1	1	1	1
	2	2	2	2
	2	2	2	2
	1	2	1	2
	3	3	3	3
	2	2	2	2
	1		1	2
	1.5	1.5	1.5	1.5
	2	2	2	2
	2	3	2	3
	3	4	data with missing value pairs removed	
	1	2		
mean	1.7678571	2.17308	**Pearson's correlation coefficient**	
s.d	0.7255803	0.97015	0.8726442	
max	3	4		
min	1	1		

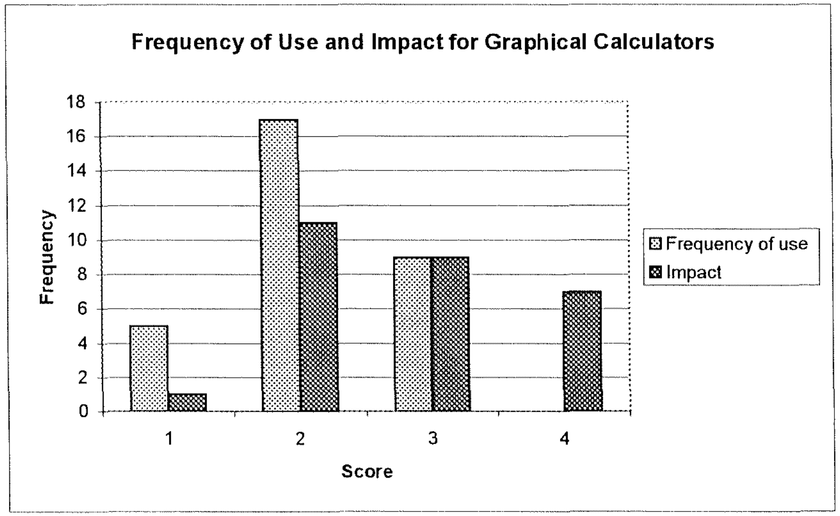
Grouped data

	frequency	Impact
1	11	7
2	12	10
3	5	6
4	0	3
	28	26



Graphical Calculators

	Full data set		Amended		Grouped data		
	frequency	Impact	frequency	Impact		frequency	Impact
	2	3	2	3	1	5	1
	2	3	2	3	2	17	11
	2	4	2	4	3	9	9
	2		2	3	4	0	7
	2	4	2	4			
	1		2	2			
	3		3	4			
	2	3	2	3			
	2	3	2	3			
	1	3	1	3			
	3	4	3	4			
	2	2	2	2			
	1	1	1	1			
	2	3	2	3			
	2	2	2	2			
	2	3	2	3			
	3	4	3	4			
	3	2	3	2			
	2	4	2	4			
	3	3	3	3			
	1	2	1	2			
	1	2	1	2			
	2	2	2	2			
	3	2	3	2			
	3	2	3	2			
	2	2	2	2			
	2	2	2	2			
	3	4	3	4			
	3	4	data with missing value pairs removed				
	2	2					
	2	3	**Pearson's correlation coefficient**				
mean	2.1290323	2.78571	0.3806754				
s.d	0.6595177	0.86011					
max	3	4					
mln	1	1					



Interactive Whiteboards

Full data set

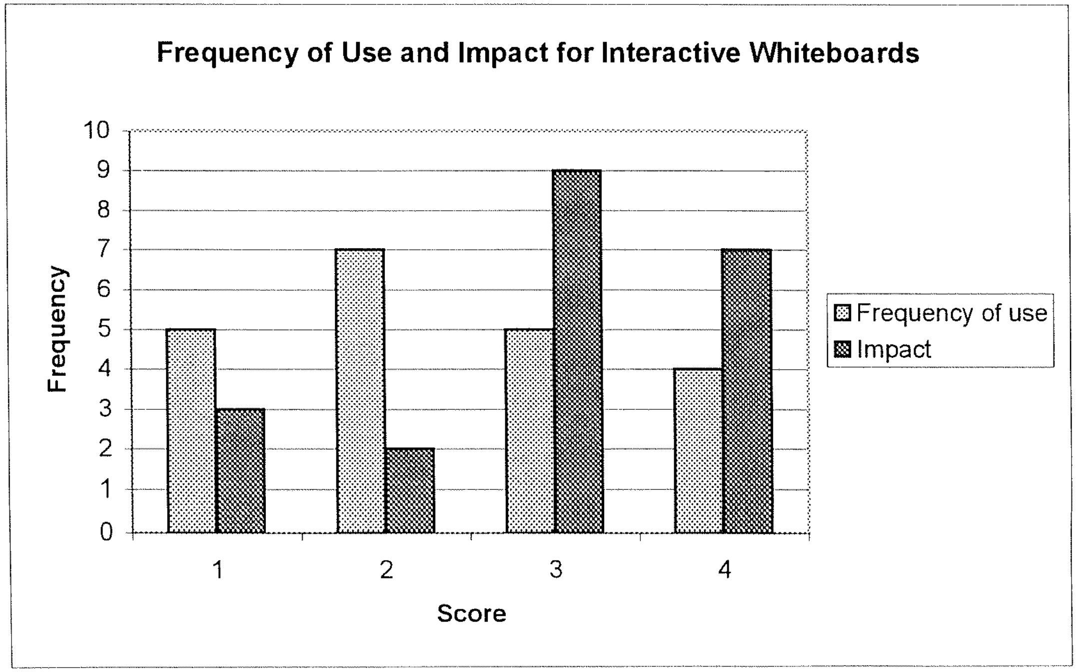
frequency	Impact
2	3
2	2
1	2
4	4
2	3
3	3
1	4
1	1
2	3
3	3
1	1
2	3
3	4
4	4
4	4
3	4
1	1
2	3
3	3
4	4
2	3

	frequency	Impact
mean	2.3809524	2.95238
s.d	1.0454523	0.99887
max	4	4
min	1	1

Pearson's correlation coefficient
0.7469793

Grouped data

	Frequency	Impact
1	5	3
2	7	2
3	5	9
4	4	7

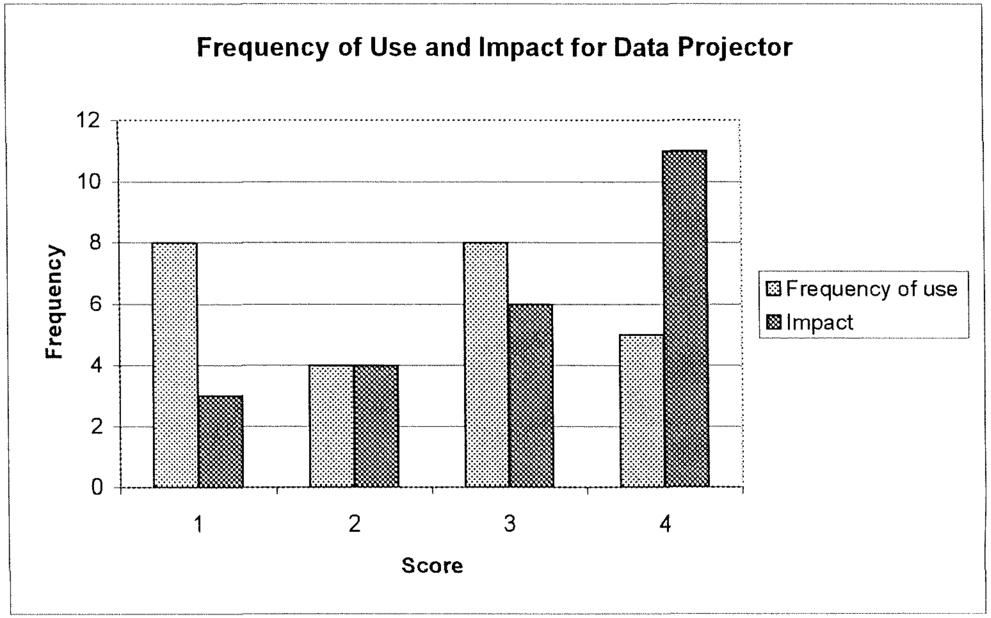


Data Projector

	Full data set		Amended	
	frequency	Impact	frequency	Impact
	4	4	4	4
	1	2	1	2
	1	3	1	3
	3	4	3	4
	1	2	1	2
	2	3	2	3
	1	1	1	1
	1	1	1	1
	1	1	1	1
	3	3	3	3
	1	2	1	2
	2	4	2	4
	3	4	3	4
	3	3	3	3
	3	4	3	4
	4	4	4	4
	4	4	4	4
	3	4	3	4
	3	4	3	4
	4	4	4	4
	2	3	2	3
	1		2	2
	3	3	3	3
	4	4	4	4
	2	2	data with missing value pairs removed	
mean	2.4	3.0417		
s.d	1.1313708	1.0598	**Pearson's correlation coefficient**	
max	4	4	0.82838431	
min	1	1		

Grouped data

	frequency	Impact
1	8	3
2	4	4
3	8	6
4	5	11

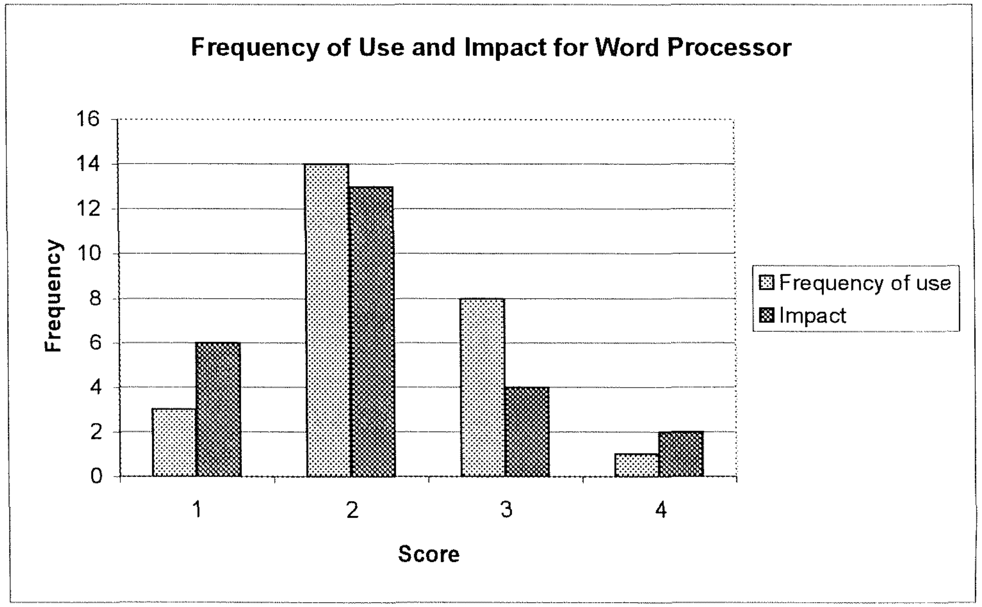


Word Processor

	Full data set		Amended data set	
	frequency	Impact	frequency	Impact
	2	2	2	2
	2	2	2	2
	3	1	3	1
	2	2	2	2
	2	2	2	2
	2		4	1
	3	2	3	2
	2	2	2	2
	3	3	3	3
	2	1	2	1
	3	2	3	2
	1	1	1	1
	2	3	2	3
	3	2	3	2
	2	2	2	2
	2	3	2	3
	1	1	1	1
	2	3	2	3
	3	4	3	4
	2	2	2	2
	3	2	3	2
	3	4	3	4
	1	2	1	2
	2	2	2	2
	2	1	2	1
	4	1	data with missing value pairs removed	
mean	2.2692308	2.08		
s.d	0.7102379	0.84475	**Pearson's correlation coefficient**	
max	4	4	0.2255393	
min	1	1		

Grouped data

	frequency	Impact
1	3	6
2	14	13
3	8	4
4	1	2

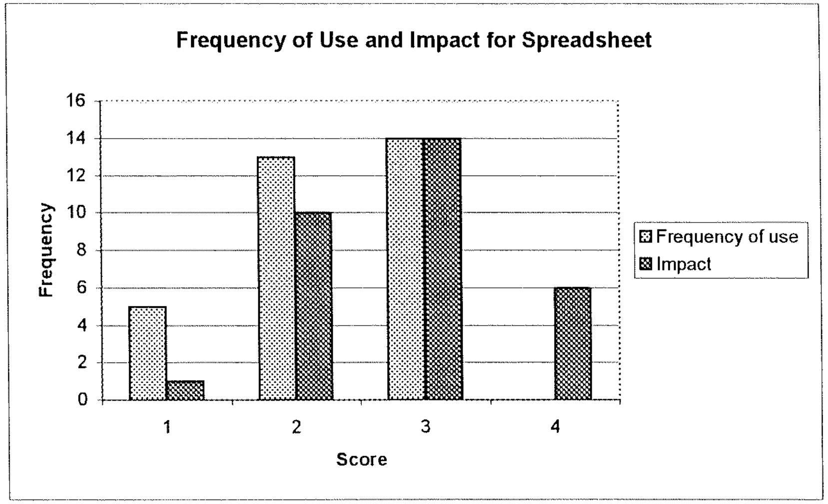


Spreadsheet

Full data set		Amended data set		Grouped data		
frequency	Impact	frequency	Impact		frequency	Impact
1	2	1	2	1	5	1
2	2	2	2	2	13	10
3	4	3	4	3	14	14
2	3	2	3	4	0	6
1	3	1	3			
3	4	3	4			
2		3	3			
3	4	3	4			
2	4	2	4			
1	2	1	2			
2	3	2	3			
3	3	3	3			
1	1	1	1			
2	3	2	3			
3	2	3	2			
3	3	3	3			
3	3	3	3			
3	4	3	4			
1	3	1	3			
2	3	2	3			
2	3	2	3			
2	2	2	2			
2	2	2	2			
3	3	3	3			
2	3	2	3			
2	3	2	3			
3	2	3	2			
2.5	2	2.5	2			
2	2	2	2			
3	4	3	4			
3	2	3	2			
3	3	data with missing value pairs removed				

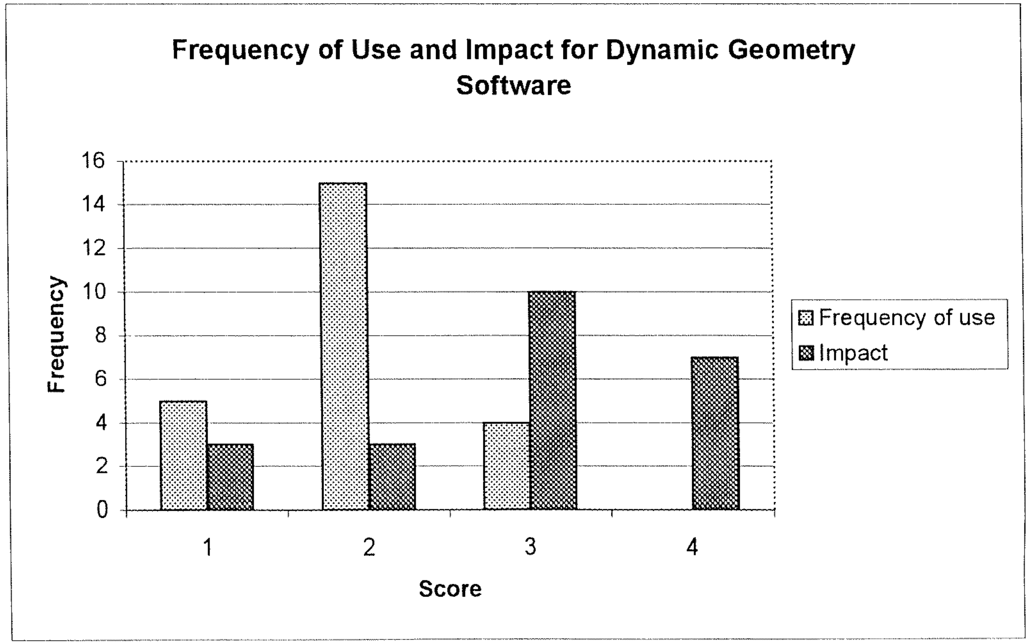
	frequency	Impact
mean	2.265625	2.8065
s.d	0.7069341	0.7796
max	3	4
min	1	1

Pearson's correlation coefficient
0.412595



Dynamic Geometry Software

Full data set		Amended		Grouped Data		
frequency	Impact	frequency	Impact		frequency	Impact
2	3	2	3	1	5	3
3	4	3	4	2	15	3
2	3	2	3	3	4	10
2	2.5	2	2.5	4	0	7
2	3	2	3			
2	3	2	3			
2	4	2	4			
2	2	2	2			
1	1	1	1			
1		2	3			
3	4	3	4			
1	2	1	2			
3	4	3	4			
2	4	2	4			
2	3	2	3			
1	1	1	1			
1	1	1	1			
2	3	2	3			
2	3	2	3			
2	3	2	3			
2	4	2	4			
2	2	2	2			
3	4	3	4			
2	3					



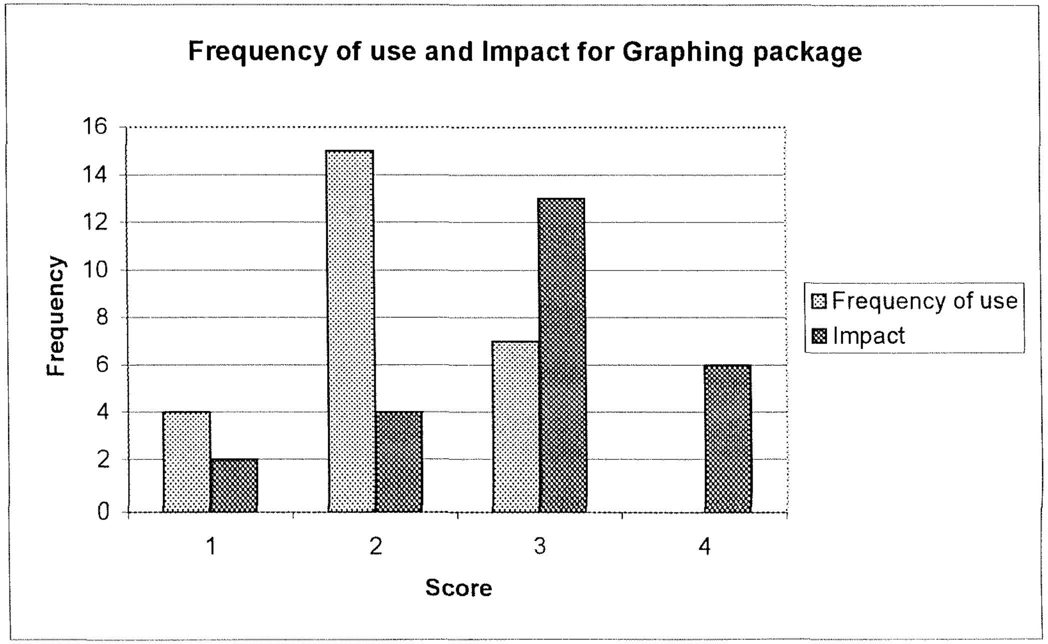
mean	1.9583333	2.8913	data with missing value pairs removed
s.d	0.6109533	0.9775	
max	3	4	**Pearson's correlation coefficient**
min	1	1	0.829566

Graphing package

	Full data set		Amended	
	frequency	Impact	frequency	Impact
	2	2	2	2
	3	4	3	4
	2	3	2	3
	2	4	2	4
	2	3	2	3
	2	3	2	3
	1	1	1	1
	1	1	1	1
	2	3	2	3
	2	2	2	2
	2	3	2	3
	1	4	1	4
	3	4	3	4
	2	3	2	3
	2	4	2	4
	3	3	3	3
	2	3	2	3
	1	2	1	2
	2	4	2	4
	2	3	2	3
	2	2	2	2
	3	2.5	3	2.5
	2.5	2.5	2.5	2.5
	3	3	3	3
	2		3	3
	3	3	data with missing value pairs removed	
mean	2.0961538	2.88		
s.d	0.6204718	0.85182	**Pearson's correlation coefficient**	

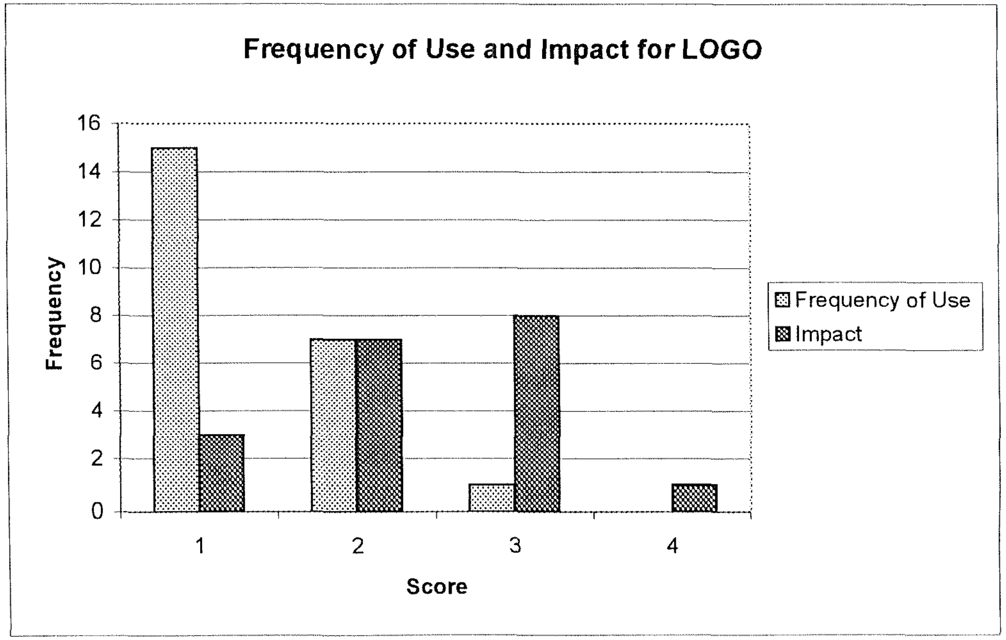
Grouped data

	frequency	Impact
1	4	2
2	15	4
3	7	13
4	0	6



Logo

Full data set		Amended		Grouped data		
frequency	Impact	frequenc	Impact		frequency	Impact
2	3	2	3	1	15	3
1	2	1	2	2	7	7
	1	1	2	3	1	8
2	2	2	2	4	0	1
2	2	2	2			
1	2.5	1	2.5			
2	2	2	2			
1	4	1	4			
1		2	3			
2	3	2	3			
1		1	3			
1	1	1	1			
1	3	1	3			
1		3	3			
1	2	1	2			
1	1	1	1			
1		2	3			
1	2	1	2			
2	3					
1						
3	3					
1	3					
2	3					
1	2					



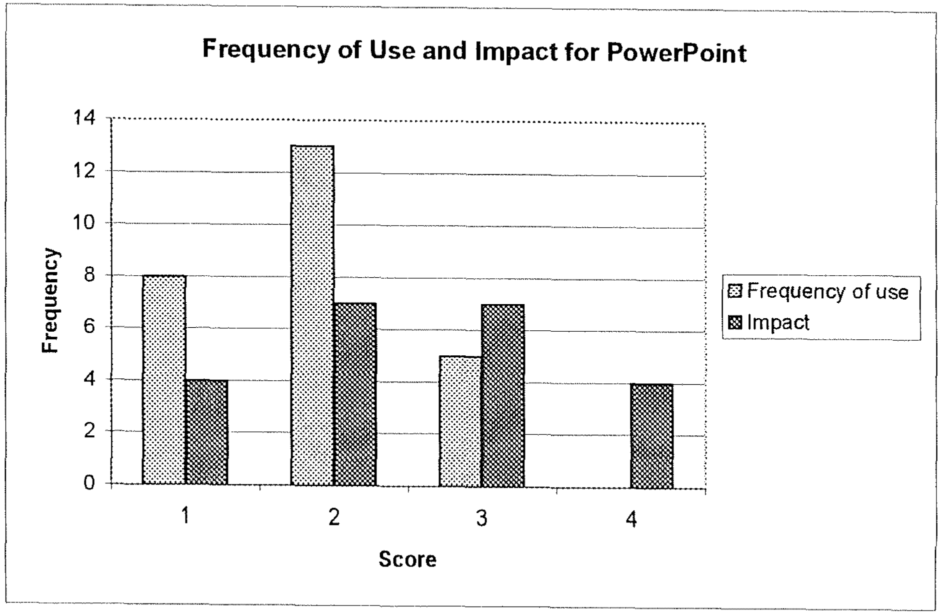
mean	1.380952	2.40625	data with missing value pairs removed
s.d	0.575383	0.774975	
max	3	4	**Pearson's correlation coefficient**
min	1	1	0.2774

PowerPoint

	Full data set		Amended	
	frequenc	Impact	frequenc	Impact
	2	4	2	4
	2	3	2	3
	2	2	2	2
	2	2	2	2
	3	3	3	3
	1		2	2
	1		1	1
	1	1	1	1
	1	1	1	1
	2	2	2	2
	1	2	1	2
	2	3	2	3
	2	3	2	3
	2	3	2	3
	3	4	3	4
	2		3	4
	1	1	1	1
	3	4	3	4
	2	3	2	3
	2	2	2	2
	2	2	2	2
	1		2.5	2.5
	2.5	2.5		
	3	4		
	1	1	data with missing value pairs removed	
	2	2		
mean	1.86538	2.47727	**Pearson's correlation coefficient**	
s.d	0.67308	0.98254	0.82016	
max	3	4		
min	1	1		

Grouped data

	frequency	Impact
1	8	4
2	13	7
3	5	7
4	0	4



Appendix H: Perceived benefits from using ICT

A

More impact

Brings it home

Different way/another way of looking at things

Brings it alive

Flexibility

More visual impact

More involvement by pupils

Increase in pace

Saving time

Extending topic

Real-life examples

Less writing/repetition/exercises

Motivation

Competitive aspects

A rare resource has impact

Increased work rate – girls don't need to spend time being neat

B

Clear presentation and layout – clarity

Pupils enjoy using it

No need to write on the board – focus is on the class

Aids those with visual memory because of the use of colour

Sound adding to memory – multisensory/multimedia approach/reading things out

Fun aspects with games

Charts, graphs, grids and scales etc. are easy.

Appendix I: Case study analysis

Ambience Enhanced

A:

They had the opportunity to see the paper folding today....Things you often want to do on a normal whiteboard but you can't

They just appreciate not having an entire lesson writing and doing exercises.

Have a complete change.....

Divide it up into different sections

The computer suite is great

Different resources...or different ways of practising

It's just a different way

It gives them another way of looking at it

Another way of looking at things

B:

...when we go in the computer room.

...if someone finds something...

....short snippets...

....the games....even if you play them for a short period of time.

Restraints Alleviated

A:

If you are doing it on paper, if you are trying to get them to draw $y = x$, $y = 2x$, $y = 3x$, *...they get bored...whereas on the computer it allows them very quickly to see what the difference is.*

...so you're saving yourself an awful lot of time

...the girls spend so long getting everything eat and tidy they quite often get behind...slows them down

they'd get bogged down sketching it by hand...

...they quite often get bogged down in detail...

without them having to actually go through and make the mistakes

without them having to sit and draw it *not having an entire lesson writing*

doing a lot more by hand

B:

With graph drawing it can be so tedious to plot the points, so slow... I think they become a bit bored if activities take too long to do

...is very good if you want o quickly draw up a grid, quickly draw up axes, scales as well.... It takes a long time to scale correctly and evenly on a whiteboard.

Tinkering Assisted

A:

...you can actually take twenty-five from both sides and they can see the equation getting more complicated without them having to actually go through and make the mistakes and putting the computer to do it correctly so that they can see what their mistakes will actually lead to.

Motivation Improved

A:

They like that, they like watching, coming up and writing on the board.

Everyone in the class likes to be involved in it

They got quite interested

They appreciate....

They still want to have a go at certain games and they like the competitive aspects of it. They like doing boys versus girls and sometimes they like even to gang up on certain people.

They like to be able to beat the computer

They still like the ability to go up to the computer room

B:

They like coming up and having a go as well. Moving things around and changing the probabilities

Pupils do like to look at the interactive whiteboard

Because the pupils can change things very quickly they stay interested

Plotting them in the computer room they enjoy it

Very keen to get the right answer, much more keen that they would be wanting the reward of a tick, the reward of getting somewhere on a game they do enjoy

Engagement Intensified

A:

The children got quite involved in seeing the data go up.... and then comparing...

We go through the process of doing it and then being able to them about how they are going to focus their own aims

I think quite a few of them have gone further than they would have done had they had to do it by hand

I think that way they are actually extending themselves further

..it will keep the group going for a good ten, fifteen minutes

Getting involved in the lesson

Lesson much more pupil involved

B:

I think they get further, learn more.

I think that aids memory

It's quite difficult to make they really want to do fractions but they do from that

Add to the excitement value

Routine Facilitated

A:

It's quicker to get a graph up and get sketches..

It gives you more time to interact with the class

Quite quickly to flip between different packages... without spending hours beforehand getting it all up on the board

That would have taken longer to do had we not had the interactive whiteboard up there...

You're saving yourselves an awful lot of time

...you can quickly get across the impression that it's the gradient that changes...you've got the facility there to get across the point without them having to plug through all the graphing...
They can go on to look at quadratics and things like that and extending themselves that way....
I can go very quickly between using line symmetry, using an Internet resource to going to reflections on Autograph without having to stop the lesson
Whereas the computer- it's all very quick and they can grasp it very quickly

B:

I think it speeds it up
...because the pupils can change things very quickly and stay interested

Activity Effected

A:

It's quicker to get a graph ad get sketches...
It enables you to quite quickly flip between different packages...
...on the computer it allows them to very quickly see what the difference is
You an quickly get across the impression
If you need to call everyone together and talk over a particular thing that's going wrong
The computer brings up the pace
There's like a hundred questions there and it will keep the group going for a good ten, fifteen minutes. Whereas if I did times tables test with them they'd be bored...

B:

...it speeds it up...

Features Accentuated

A:

Transformations is quite visual so it obviously suits the whiteboard a lot easier
It brings it alive for them
Things you often want to do on a normal whiteboard but can't

They can see things appearing in front of their eyes

Rather than doing a lesson and saying 'What happens here… ' you can see it.

Gave you the flexibility to actually bring it alive for them

It brings it alive for them

Bringing things alive

B:

The layout was nice and clear…

The fact they'd used colour…

It was very clearly written and there could be no doubt about what a number was and which numbers were being highlighted. It just added to the clarity and with them seeing the colours on the board

Which is clearer when there's colour involved

There's often bits of sound attached

…very good if you want or quickly draw up a grid, quickly draw up axes, scales as well, so decimal work, drawing scales. Again it's much clearer. Much better than me drawing it on the board.

I thought it was nice and clear

It's lovely and simple. It saves you having to actually have the beads in jars as well. You have them up on the screen. It's clear for the pupils.

Nice, straightforward.

Added to the clarity again.

Attention Raised

A:

We'd have spent a lot more time reviewing stuff that they should already know

They don't have to think about how they go about plotting it. You are looking at things like what the gradient is…what's happening that you are interested in. Not whether not they can draw the graph that goes with it. …

Especially the girls spend so long getting everything neat and tidy they quite often get behind…

They'd get bogged down in the peraphnailia of sketching it by hand…

There's nothing particularly difficult about looking at the shapes these curves have, it's the drawing behind them...
Get bogged down in detail...
Without having to sit and draw it

B:

It can be so tedious to plot the points and so slow to plot the points,... if you're plotting them in the computer room they enjoy it and I think they get further, learn more.

Ideas Established

A:

We go through the process of doing it and them being able to think how they are going to focus their own aims...
You can quickly get across the impression that it's the gradient that gets bigger...
Quite a few of them have gone further than they would have done had they had to do it by hand
They can see what their mistakes will actually lead to

Investigation Promoted

A:

They've been able to talk pupils through the kinds of things they might want to do
The icecream scoops for example I had some of the things we did, last lesson we looked at this, we did this, you've got to make sure you've got your introduction there, your method, your table of results.....

Consolidation Supported

A:

One of the things we do for numeracy is to use the BBC Skillwise web site... times tables tests..
If they can play a game against the computer...
They like to know whether or not they're in the right place and get the feedback that way

They can get instant feedback on questions there....So yes, it's always an advantage if you can give feedback to pupils as soon as possible if you have the facility to do that.

B:

The game I planned to use at the end was revising on the topic which was really factors and multiples and primes.
Playing 'Haunted House' they get very worked up as the ghost gets nearer, very keen to get the right answer....There's also a nice slalom skier to so with changing from mixed numbers to improper fractions and back again.

Appendix J: Additional proposed themes

Using real-life examples

A:

When we use the Internet resources that are out there it brings in real-life examples as well, you can see where its used in real-life.

B:

It's based on conceptual learning and going around, for example, what does it mean to have a mortgage, something like that, and using the maths involved to educate themselves in the wider world.

Classroom Management

A:

You have your back turned to the class for longer....more time to interact with the class.
Keep an eye on the class a lot more of the time.

B:

It saved me form having to turn my back on the class and write on the board all the time.

Reviewing previous material

A:

It's very good for having there... bring up past lessons on it... I had some of the things we did, last lesson we looked at this, we did this,... very good for bringing up past lessons.
Oh, you've got a bit fast there, can you just go back to the previous one?...It's always there, so they an refer back to it if I've gone too fast or they haven't quite caught up.

Glossary

BECTa British Education and Communications Technology Agency

BESA British Educational Suppliers Association

CAS Computer Algebra Systems

DfES Department for Education and Skills (U.K.)

ICT Information Communications Technology

ILS Integrated Learning System

NAEP National Assessment of Educational Progress (U.S.A.)

NOF New Opportunities Fund

Ofsted Office for Standards in Education

QCA Qualifications and Curriculum Authority