MATHEMATICS, ICT AND EFFECTIVE TEACHING

Rod Bramald
University of Newcastle upon Tyne
< Rod.Bramald@ncl.ac.uk>

Steve Higgins
University of Newcastle upon Tyne
<s.e.higgins@ncl.ac.uk>

This paper reports some initial findings from a substantial project funded by a UK government agency. The project aimed to investigate effective pedagogy in numeracy and literacy using ICT in primary schools. Some preliminary findings relating to pupils' attainment and a series of lesson observations are reported. Some of the broader findings from the development work in mathematics and ICT are also discussed in the context of two particular case studies which focused on developing effective pedagogy in mathematics.

INTRODUCTION

This paper describes some aspects of a two year project investigating effective pedagogy in numeracy and literacy in primary schools (for 4-11 years) in England. The research was funded by the Teacher Training Agency (TTA), a government body responsible for the initial teacher training curriculum, standards and continuing professional development of teachers. Although the final report of the project will not be published until the middle of 1999 some of the implications from specific parts are discussed here, particularly in relation to mathematics teaching and the effective use of Information and Communications Technology (ICT). In England there is considerable change taking place in the teaching of mathematics in the primary age range. At the same time the government is funding, from the UK National Lottery, training for all serving teachers to develop their skills in the use of ICT in their teaching. This paper discusses some of the observations of mathematics teaching from the project, some of the work of the project team concerning teachers' thinking about ICT and some relationships with their practices as well as presenting two of the development projects as brief case studies. We then draw out what we see as some of the overall implications for effective development work in mathematics and ICT.

THE RESEARCH PROJECT

As part of its remit to improve the quality of teaching in England, the TTA commissioned the University of Newcastle to undertake research into effective classroom pedagogy using ICT in primary schools. The TTA intended that this research should:

- test and develop a generic framework highlighting the potential benefits and pitfalls of using ICT in classrooms, particularly in the areas of numeracy and literacy;
- help teachers raise pupil achievements in these areas through supporting informed choice about the use of ICT in the classroom;
- refine and illustrate specific aspects of ICT use through "rich pictures" - detailed classroom case studies of effective teacher practice and development.

The research was carried out in three main stages. During the first stage, a range of schools was identified and the extent of ICT provision determined. Some of the schools were identified using value-added (VA) data from the Performance Indicators in Primary Schools Project (PIPS) based at Durham University, initially through a brief postcard survey (2053 schools: 66% return rate). The postcard survey yielded data for 740 classes for which 1996-7 value-added scores were available. Then, to ensure the aims of investigating effective pedagogy were met, a sample of only those teachers who were identified as having high or average VA was selected. This enabled correlational links to be examined between a more detailed follow up questionnaire and the VA performance data from the schools to identify any factors which were distinguishing characteristics of the high VA teachers. At this stage, 250 questionnaire returns were received (a response rate of 34%). In the second stage of the project specific teachers from these schools and other 'ICT-rich' schools were investigated to identify pedagogical factors which correlated with increased pupil attainment. Structured observations of four lessons in each of 32 classrooms were compared with data on pupils' performance. In the final stage of the project, data from the questionnaire, the observations and existing research information were used to plan specific development projects in numeracy and literacy with 20 teachers in their own classrooms. Evidence for the effectiveness or otherwise of this development was focused upon pupil attainment using standardised tests. In addition further observations and interviews with teachers were completed. Then a construct elicitation exercise was undertaken with teachers to investigate their thinking and beliefs about teaching and learning.

Value Added (VA) and PIPS

PIPS is one of a series of performance indicator (PI) systems used in monitoring education. They were developed originally by Prof. C.T. Fitz-Gibbon (see Fitz-Gibbon 1996 for details) and all use VA scores as their basis. VA data are measures of relative performance calculated annually at the individual pupil level. They are based upon a model which uses a least squares regression analysis technique resulting in relative residuals. The model requires very large numbers of pupils in each cohort - PIPS currently has approximately a third of a million pupils involved each year. Individuals' scores in a variety of tests are measured using material which has been shown in independent research to be the best available predictors of future performance. For each child, a predicted score is calculated using their individual input variable scores. Their actual achievement score is then compared to this. For example, a child in maths may score 50 and the model predicted 45. S/he would have a relative residual of +5. Clearly, any child achieving the same score as their predicted score will have a VA of zero. For the purposes of this project, these individual VAs were aggregated up to teacher level. A teacher whose pupils' aggregated score is zero is taken to be 'averagely effective' whereas one whose pupils' scores are significantly positive is said to be 'highly effectively'.

SOME ASSOCIATIONS BETWEEN QUESTIONNAIRE DATA, THE OBSERVATION DATA AND PUPILS' ATTAINMENT

Analyses of the initial postcard survey data were carried out to see if high computer use across a school year group was linked with high levels of achievement, high VA scores or very positive attitudes. Generally there was little evidence for this. There was almost no association between the reported amount of computer use and either achievement level or attitude. However there was a relationship with VA in that the small number of year groups where pupils were said to use computers "more than once a day" had positive VA scores on average. Year groups where pupils used computers "less than once a month" had negative VA scores on average. This suggested that, at the extremes, highly effective teachers tended to have pupils using computers a lot and less effective teachers have pupils using them rather infrequently. The effect size differences between the high and low groups were 0.6 for mathematics and 0.4 for reading, with the most significant result applying to mathematics VA in Reception classes (4-5 year olds). This clearly implies that Reception teachers who are particularly effective in mathematics tend to use computers more often in the classroom. This finding was validated to some extent by a connection between pupil VA scores in mathematics for Reception teachers taking part in the development work who also reported greater use of computers for number work (a correlation of 0.53, but non-significant, due in part at least to the small number of Reception teachers (8) involved in development work).

Some significant relationships between the first set of lesson observations (on four lessons with each of 32 teachers) conducted by the project team and the VA scores of the pupils were also found.

Teacher Behaviours

(Please note: * indicates significance at the 0.05 level and ** at the 0.01 level)

- Highly effective teachers used more examples and counter examples (0.61**) in numeracy lessons, particularly in the plenary phase of the lesson (0.41*). For example a teacher might give an example of an incorrect solution as well as a correct solution and explain why one was correct and the other incorrect. *(This was a particularly strong relationship and suggests that effective teachers use examples as part of their teaching but also exemplify what they are teaching with counter examples for clarification.)*
- Highly effective teachers of Reception classes (4-5 years) tended to provide different ICT activities for pupils with special educational needs (SEN) from those for the rest of the class (a correlation of 0.75* with VA scores for the eight teachers who reported providing such activities). The opposite trend appears for teachers of older pupils (classes of 6-7 years and 8-9 years), though the correlation was not significant.

Pupil Behaviours

- Pupils tended to model work as examples to their group or the rest of the class in the highly effective teachers' classes (a correlation of 0.51** with VA scores for the 32 teachers observed).
- Pupils tended provide examples more in the highly effective teachers' classes (a correlation of 0.45*): these last two findings are clearly linked, though some caution in interpreting this result is called for. The frequency of pupils' examples in the final plenary phase of the lesson does not seem to be so clearly beneficial. Such pupil behaviours in the final phase of the lesson were negatively associated with value-added scores, a correlation of -0.42 (ns) was found for the 18 teachers for whom data was available.

We interpret these findings as indicating that effective teachers make good use of clear explanations, perhaps an unsurprising result and one which reinforces the work of other researchers (e.g. Dunkin and Biddle's (1974) review of classroom research from the 1960s and early '70s or Rosenshine's work (1983)

IDENTIFYING AND OVERCOMING BARRIERS IN USING ICT TO ENHANCE TEACHING AND LEARNING IN CLASSROOMS

Part of the challenge set by the TTA was to summarise existing work on identifying and overcoming barriers to using ICT effectively in the classroom; to exemplify some of these barriers and the way the project team tackled them through the development work in schools; and finally, to suggest ways of understanding these barriers as a means to overcoming them.

The task was approached in several different ways. Many different barriers were identified and these fell into various categories. *Time* related issues were consistently identified as the biggest group. The next set appeared to be *equipment* related and this was followed by *pupil* related ones. It was possible to make a clear distinction between issues relating to people and those relating to equipment: e.g. the number of pupils in my class; the amount of adult support; and the number of machines available for the pupils to use. Perhaps the most important pedagogical issue identified was knowing which software was appropriate in a given situation. However, in general, these pedagogical barriers which teachers identified were seen by them as relatively less important than the other barriers indicated above. These findings match closely the 'problems and challenges' recently reported in Scotland (William's et al, 1998)

Later, in a group discussion with some of the teachers, several significant issues were again raised: it is difficult for teachers to devote time to only two or three pupils who are working on computers; the number of computers per classroom is still low (usually one, occasionally two); the time needed for teachers to learn new software appears to be increasing with the complexity and sophistication of the software; the time for some to learn how to use basic software for word-processing or data handling well; the lack of immediately available technical support; past frustrations, especially with printers, leading to de-motivation and the ever growing cost of consumables.

A different sub-set of teachers from the original questionnaire was also surveyed (120 teachers, 53% return) and asked to self-rate how confident they felt to tackle particular tasks using ICT. Their responses (n=64) suggest that confidence in using ICT is still a challenging issue for primary teachers. Only *using a spell checker* was an area where the average score indicated that teachers were confident to tackle the task.

The team also tried to explore positive examples of overcoming barriers and several factors were identified as being related to this: supporting the development of pupils' skills to enable a clear focus on objectives in numeracy or literacy; providing information about software, but again with specific subject-related objectives in mind; finding ways to increase access for pupils and providing copies of software for teachers to use at home. In subsequent interviews, teachers reported that offering technical support and supporting their personal skills had a positive impact on their attitudes and confidence.

Further study of our data revealed that teachers with high VA scores: (a) tended to report that computers made them feel good about their teaching; (b) thought that computers did not require too much technical knowledge and (c) said that computer software was not too complicated for children. Since these data were strongly associated with highly effective teachers, it suggests to us that such teachers see the potential of the technology and try to use it effectively by integrating it as part of their repertoire of teaching strategies and approaches. In the same way the team feel that the barriers are seen by some teachers as something which is to be overcome and by others as more of a barricade which prevents them realising the potential of ICT. To use Leat's (1999) metaphor, for these teachers it is a case of rolling the stone *uphill*. For the former grouping, those who may have needed help at first, it is more a case of rolling a stone *downhill*. Once barriers have been overcome the development work gains momentum and overcoming barriers becomes less of an issue as the teacher's skills and confidence increase. On the other hand, for a few teachers in the project, once one barrier is addressed and overcome, another appears. Rolling the stone uphill in this case becomes more like the task of Sisyphus, as once your back is turned the stone seems to return to the bottom of the hill.

To summarise this section, teachers identified ICT-specific barriers as a major difficulty in their attempts to become more effective in using ICT in the classroom. They did not identify subject-specific factors in numeracy or literacy or general pedagogical issues. In some cases these ICT-specific barriers were overcome relatively quickly and easily. In others, these barriers were not overcome easily and required a determined effort on the part of the development team and the teachers involved. All of the information discussed above was used by the team as background to planning specific interventions with 20 teachers in numeracy and literacy, two of which are now described in more detail.

CASE STUDY 1: DEVELOPING COUNTING SKILLS WITH RECEPTION PUPILS USING ICT

This case study focused on developing counting skills with 4-5 year old pupils. The pupils created counting pictures using a children's drawing and painting program[1]. The activities were designed to complement other numeracy activities and to act as a focus for discussion between the researcher and the teacher. The development work took place over two terms with two different classes of pupils. The results from the standardised testing[2] suggest that teacher was able to use ICT effectively as part of her teaching to support the development of her pupils' counting skills. Using detailed knowledge of how young children learn to count and the errors that they commonly make was an important feature of the development work in ICT and mathematics.

The teacher has been at the school for six years and usually teaches the Reception Year. When planning activities she likes to make links between different activities and to draw out connections for the children. *".... they might need work on number recognition, or using number lines, and it isn't always linked. But usually we do something that is to do with counting, a counting rhyme or acting out a song which is linked to other activities."* This approach is consistent with the new National Numeracy Framework's (Department for Education and Employment, 1998) recommendations for the Reception year currently being introduced in England and with recent research on effective teachers of mathematics (Askew et al, 1997).

At the beginning of the Summer term, some pupils were making errors in reciting the number names accurately (particularly numbers from 13-19 and at the decade transitions such as 29 to 30), some had inaccurate one:one touch counting skills and strategies which led them to give an incorrect total at the end of a count, and some were also unable to identify the correct numeral to go with a number name with numbers up to 20. These matched previous findings of other researchers such as Denvir and Brown (1986) and Maclellan (1997). The teacher was therefore keen to address these issues in a broader way. She saw ICT as enabling her to do this more effectively than she had been able to do with previously available software which focused only on numeral recognition. *"(It) was quite different from anything (that) I've used before, (which) had been very closed."*

The teacher found the diagnostic information from the baseline test very useful. It gave her detailed information about the particular counting errors that specific pupils were making. In addition to the work using ICT she planned other numeracy activities to address pupils' particular difficulties. The teacher wanted pupils to be able to practise specific aspects of counting and therefore emphasised different counting skills with different children. The software has the facility to let children stamp a variety of pictures onto the screen thus allowing them to work on the different aspects of counting which had been identified in the initial assessment.

The teacher thought that having pupils create mathematical pictures, and count out loud as they did so, enabled them to use the ICT more independently. They were able to create a variety of pictures over a period of several weeks. This matched a number of the teacher's mathematical objectives for the term such as using their counting vocabulary, improving the reliability of their counting, teaching them more systematic counting strategies and helping them to recognise and use numerals. *"We didn't have much in the way of numeracy materials, whereas using the (ICT) has really helped, and the children have used a lot more mathematical language."*

A target group of five pupils was identified whom the teacher thought would benefit from the ICT work, together with a control group of 3 others. A standardised test was used to assess children before and after intervention. The target pupils all showed that their counting and number ability in particular had improved. They had also improved relative to the other three pupils (an average of 8 point gain in age-standardised score compared with an average gain of 1 for the control group). This development work was repeated in the Autumn term with the teacher's next class, but without a control group. The class made impressive gains. Their age-standardised score improved by an average of 15 points in just over two months.

It is clearly not possible to claim that the pupil score improvements were directly due on either occasion to the ICT activities, especially as the teacher used the information from the standardised test to inform her planning more broadly. However the results do suggest that carefully planned and structured ICT activities with clear mathematical objectives can play an effective role in improving pupils' counting skills.

CASE STUDY 2: DEVELOPING UNDERSTANDING OF DECIMALS WITH Y4 PUPILS (8-9 YEARS) USING PORTABLE ICT EQUIPMENT

In this case study, the teacher wanted to introduce her class to decimal notation. The school's mathematics policy, like many others, follows very closely the National Curriculum and so she felt she was almost directed to teach this through the medium of money notation. However, in the UK there is a culturally related problem which makes this quite complex. £3.24 is not seen as a single number of pounds but rather as two closely related numbers: three pounds and, separately, twenty four pennies. This leads to the common error of writing the amount as £3.24p. It is almost as if we have an Imperial notation imposed on a metric system. The result is that for teachers of 8-9 year olds, this becomes an unnecessarily difficult hurdle when teaching decimal number, so one of the teacher's main concerns was the issue of how meaningful the pupils would find such decimal numbers. Given that she eventually wanted her pupils to be able to order and even calculate with decimal numbers, she felt that it was important to use numbers where the pupils could draw some understanding from the context.

After discussing matters with the Project Team member, she agreed to try using *time* as the medium rather than money - time measured through the use of ICT. The activity used an e-Mate (a robust portable computer designed for children) connected to a pressure-mat sensor. This allowed the children to generate times in seconds to two places of decimals. The equipment enabled two different types of activities to be timed, each of which needed different interpretations as to which was the 'best'. The first activity required the children to stand on the pressure mat and jump in the air before landing on the mat again. The times for these standing jumps were typically 0.43 or 0.37 seconds. Here, the 'best' time was the biggest number - the longest time in the air. The second activity exploited the portability of the equipment as the children used the ICT equipment as a timing gate. They took it out into the playground and ran from one side to the other and back again. As they set off, they trod on the mat starting the timer. It stopped when they returned and trod on it again. Here the 'best' time was the smallest number - the shortest time taken.

The teacher chose to use the ICT equipment for two reasons. The first was to generate 'real' numbers which the children could understand from the context in which they were produced. The second was as a stimulus to get the children thinking about what 'best' meant and about using decimals in a specific context to achieve this. She also wanted to use aspects of the published scheme which the school uses as part of its approach to mathematics throughout the school but also to make links to understanding decimals in another way through the ICT activity. Using the ICT also had an effect upon the choices related to her expectations of the children. She had not done a lot work on decimals with previous Y4 classes. This, she thought, might have been related to her own needs as well as those of the children.

> "I found decimal fractions quite difficult for a lot of children. It may be the fact that I didn't expect them to take it much further that was part of my problem as well. The e-Mate stimulated their interest to learn and understand beyond my expectations. I would never in my wildest dreams have thought they would cope with this."

Not only was there a global shift in her expectations of what the whole class could achieve, but there was also a few significantly different changes for individuals.

The pupils completed a standardised mathematics test[3] before and after the intervention. The results indicate that the mean number-age rose from 8 years and 4 months to 9 years and 5 months. This gain was achieved in four months. (The difference is statistically significant at <.001 level.) The test did not specifically look at using decimals, although that skill was a component of the test. Whilst it is important not to attribute this gain solely to the ICT activities, it is thought reasonable to suggest that they will have played a part in developing specific mathematical skills and understanding. In addition, it also seems reasonable to assume that they will also have played a part in the more general improvement in the pupils' confidence and attitude. The idea that working on developing one area of mathematics has a non-planned but significantly beneficial effect upon others is consistent with the work of Denvir & Brown (1986) and is therefore not surprising.

SOME CONCLUSIONS AND IMPLICATIONS

Obviously we have to be somewhat cautious about over-stating any claim based solely upon this work, but there are some interesting outcomes. It appears that effective teachers use examples and counter examples as part of their normal teaching. The pupils of such teachers tend give examples during lessons and to model their work both when talking to the teacher and to their peers.

The teachers' and the pupils' levels of personal confidence appear to have conspicuous effects upon the outcomes when measured through pupil achievement. What is more, the degree of their confidence in using ICT appears to be rooted quite firmly in their personal skill levels. Our data would support the view that, on the whole, effective teachers who use ICT are teachers who are confident with ICT and that they are much more comfortable with ICT as an enabling addition to their pedagogical armoury. Where ICT is not adopted as a normal part of their teaching, certain barriers play important parts in determining whether and how teachers in primary schools adopt ICT in their teaching. In trying to explore this, the research team found that if the specific ICT-related issues were addressed head-on, this would not necessarily lead to future success for the teacher. What we felt was important was to try to work around the problem rather than to confront it. This was done by helping the teachers to keep a very clear focus upon desired mathematical content targets for the lesson(s) and not to get side-tracked into the ICT issues. Principally, this was achieved by having someone in their classroom helping to get their pupils over an initial threshold of personal ICT skills which allowed the teachers to concentrate upon the mathematical purpose of the lesson. Using this approach, it was as if the original hurdles were by-passed rather than confronted. The result was that the importance of solving ICT issues diminished considerably. Once past this hurdle, it was as if the changes became self-fuelling and the teachers began to use the ICT to achieve improvements in their teaching without further help. ICT was seen as insufficient in itself to stimulate changes in their pedagogy. However given assistance to get their pupils sufficient skills to then concentrate upon the mathematical task in hand (rather than the technicalities of using the equipment), they could achieve some surprising results - surprising often to themselves as well as to outside observers. We believe this may well have implications for a UK government which seems to believe that the large scale and very expensive adoption of ICT could be an important factor in solving a pressing teacher shortage.

The data and case studies presented here are only a small selection of the initial findings from a substantial, very data-rich project and do not attempt to be a complete report of all that has been measured and analysed. They are seen as being principally illustrative and not conclusive. Possibly the most important thing to say is that whilst many of results reported are correlational, the team are crucially aware that there should be no attempt to suggest that there is necessarily any causal link implied or intended, only that the findings may well indicate areas where more detailed and carefully structured investigation may be necessary to establish firmer links. However, we believe there are some very interesting and possibly important findings that may well prove to be significantly influential in the future.

At this stage of our research however, and somewhat fundamentally, we conclude with two points: first, we cannot see machines replacing the essential element of the personal relationship that exists between teacher and pupil in the primary years of schooling, though the addition of new technologies may enhance this teaching and learning relationship, and, second, we would not want to underestimate the effect of the personal relationship which develops between teachers and those supporting their professional development as an important factor in successful development.

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Endnotes

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[2] Early Mathematics Concepts, (1997) NFER-NELSON Pub. Co. Ltd.

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