A PRACTITIONER MODEL OF THE SUCCESSFUL USE OF COMPUTER-BASED TOOLS AND RESOURCES TO SUPPORT MATHEMATICS TEACHING AND LEARNING

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This study analyses the pedagogical ideas underpinning teachers' accounts of the successful use of computer-based tools and resources to support the teaching and learning of mathematics. These accounts were elicited through group interviews with the mathematics departments in seven English secondary schools, conducted in the first half of 2000. The central themes are organised to form a pedagogical model, capable of informing use of such technologies in classroom teaching, and of generating theoretical conjectures for future research.

RESEARCH INTO COMPUTER USE IN SCHOOL MATHEMATICS

Although there has long been interest in the potential of computer-based tools and resources in school mathematics, their use has only recently become more established in mainstream practice. An indication of the extent of such use is provided by the recent international surveys (Beaton et al. 1996; Mullis et al., 2000). In the first, England was the system with easily the largest proportion of students reporting computer use. In the second, England was joined by Singapore, the system showing by far the most marked increase over the intervening period. Typically across systems, however, computer use remains low, and its growth slow. Against this background, it is not surprising that focused studies of computer use in school mathematics have largely examined explicitly innovative situations, usually linked to development projects of some type.

More recently -and very predominantly in the United States- studies have started to examine the evolution of computer use beyond situations of innovation, in circumstances where it has become more ordinary than innovatory, more established in operation than consciously under development. Surveys have provided a simple profile of the forms of computer use taking place, and of pedagogical orientations associated with them (Becker et al., 1999; Niederhauser & Stoddart, 2001). However, the reports of these surveys themselves highlight some of the limitations of employing preconceived models and questionnaire items to capture teachers' perspectives and practices. Case studies based on interview and observation have offered a useful complement to such surveys, providing more naturalistic and holistic accounts of the perspectives and practices of individual teachers (Myhre, 1998; Doerr & Zangor, 2000). However, the focus on individuals restricts the capacity for analysis across cases, and thus for building theories and models with stronger potential for transferability and generalisability.

DESIGN OF A STUDY OF TEACHER CONCEPTIONS OF ICT USE

The study to be reported here develops this line of enquiry into how teachers conceive their incorporation of use of computer tools and resources into mainstream mathematics teaching. It complements previous studies by extending such research to England, where the use of computer-based tools and resources, commonly referred to as information and communications technology (ICT), has been a component of the national curriculum for over a decade; and by following a somewhat different theoretical orientation, and employing correspondingly different methods.

Two intellectual traditions have influenced the theoretical orientation of this study. The first is a naturalistic tradition of research into teaching which has insisted on the necessity of attending to teacher thinking, not just as an important component of the phenomenon under investigation, but as a crucial source of constructs with which to build more potent theories (Brown & McIntyre, 1993; Cooper & McIntyre, 1996). The second tradition is a cultural psychological one concerned with collective systems and inter-subjective processes of thought, which emphasises not only the social dimension of thought, but the distinctive forms of everyday thinking (Moscovici, 1981; Wertsch, 1991). The concern here is to explore the content and form of 'common sense' thinking, focusing on public norms over personal variants.

The contemporary circumstances of teaching accentuate this stance. In England, the subject department acts as a basic unit within secondary schools for the formal organisation of teaching and the informal association of teachers. Recent educational reforms, too, have led to departments playing an active part in mediating between national regulations and classroom teaching, through the development of schemes of work. Hence, the unit of observation for this study was the school department, and the concern with shared systems of ideas.

The study drew on group interviews held with the mathematics departments in seven non-selective schools working in an established partnership with the university. Access to ICT in these departments varied considerably, but all made some use of it in their teaching. The interviews proceeded from a positive stance, with the main prompt requesting examples of ICT use which participants felt had been successful in supporting teaching and learning. The audio-taped sessions were transcribed and edited, and the resulting transcripts imported into a computer database to facilitate a recursive process of thematic organisation through constant comparison. This led to the construction of prototypical categories, grouping together related material. The goal was to identify well developed themes running across transcripts, and relationships between them.

THEMATIC ANALYSIS OF CONCEPTIONS OF SUCCESS

Initial analysis focused on the *success themes* which were explicit or implicit in teacher accounts. It appeared that these themes could be conceptualised in terms of three related priorities, concerned with securing and enhancing the participation of students in classroom work, the pace and productivity of such work, and the

progression in learning arising from it. Two quotations will be used to illustrate these success themes. The choice of these particular quotations reflects an emphasis on the part of the teachers. Although they referred to a range of ICT tools and resources, it was the use of various forms of calculator or computer graphing which attracted a disproportionate amount of comment. Equally, these particular quotations illustrate how these references to use of graphing technology covered the full age and ability range at secondary level: from the academically lowest class in the youngest age cohort; to the academically highest course in the oldest age cohort:

> We've used spreadsheets in Year 7 and 8, to enable them to look at handling data, because they can quickly get tables and produce charts that are much better quality than those that they can produce themselves. I've got the bottom set in Year 7 and it can take them the whole lesson to draw a bar chart. So it's particularly successful from that point of view... because they don't have to draw all the axes so much, and it doesn't take them so long to develop the ideas because they're not having to spend a whole lesson drawing something. They can draw twenty graphs in a lesson and actually see connections, rather than spend twenty minutes drawing the axes and then twenty minutes talking and then twenty minutes drawing all the graph. [VC]

> It saves a lot of time as well with the Further Maths and the graphing that we did. It would have taken forever to actually plot all the points and see what happens when you transform certain shapes. Whereas it was done in a flash and they could see and they learnt an awful lot. So then they were ready and they'd accepted it because they'd seen it happening... Whereas it would have taken many lessons if we'd actually plotted all these graphs, they'd have just got bored by it. So that definitely helped, just kept the pace going. [MC]

Both these quotations appeal to comparisons with similar activities conducted without access to computer graphing tools. Issues of participation are framed in terms of avoidance of disengagement ('twenty minutes talking') and demotivation ('just g[etting] bored by it') on the part of students. Issues of pace and productivity are framed in terms of time saved and pace maintained ('it doesn't take them so long'; 'it saves a lot of time', 'it would have taken many lessons', 'just kept the pace going') and work produced ('they can draw twenty graphs in a lesson'). Issues of progression are framed in terms of ideas being formed ('actually see connections'; 'see what happens when you transform certain shapes') and embraced ('they'd accepted it because they'd seen it happening'), and in more general terms of development and learning ('to develop the ideas'; they learnt an awful lot').

THEMATIC ANALYSIS OF CONCEPTIONS OF PROCESS

These success themes provided a useful basis for further analysis to identify the technological affordances and mediating processes which teachers saw as underpinning these forms of success. From this further analysis, ten *process themes* emerged as prominent across the departmental interviews. These will now be outlined and sparingly illustrated (due to limitations of space).

The theme of *Ambience enhanced* associates ICT use with change, difference or variety in working ambience. This was sometimes a matter of change of working location -from ordinary classroom to computer classroom- and correspondingly of work organisation. Where technology use was seen as something of a break from 'routine', such motivational effects could be attributed to the novelty of the situation, or to the conferment of privilege. Typically, too, work in the computer classroom involved students interacting directly with a machine; but also, given the normal situation in which the number of class members was around double the number of machines available, students often worked not individually but in pairs. But even in an ordinary classroom, with teacher-led activities directed at the whole class, an interactive style of ICT use created a distinctive feel:

> I've only this week been using a program, just a short one, for the students to input a number, which it then outputs following a rule, so they can try and spot the rule by choosing different inputs and seeing what the outputs are. They quite enjoy seeing things done in a different way. [VC]

It seems that it was such exploratory, interactive styles which led to ICT use sometimes being characterised -in a wholly unpejorative way- as 'playing around' and the devices themselves as 'toys'. Teachers talked of the 'variety', of the 'difference', even of the 'other dimensions', associated with ICT use, and related these to securing and enhancing student participation in classroom activities:

The theme of *Restraints alleviated* associates ICT use with the alleviation or mitigation of factors restraining or inhibiting the participation of students in classroom work. One important sub-theme (related to the 'play' sub-theme of Ambience enhanced) concerned the capacity of ICT use to prevent 'work' becoming 'drudgery'. A further sub-theme focused on the way in which ICT use is often associated with a reduction -or removal- of the writing demands -physical and intellectual- of much conventional classwork; demands which may deter or challenge some students. Another specific area where weakness in student capacity was seen as alleviated by access to technology was the drawing of graphs: A final sub-theme concerns the way in which ICT use changes the status of mistakes, not only by facilitating their correction, but by removing evidence of them which might attract unwelcome -and demotivating- attention from the teacher:

> They don't seem to mind getting things wrong either. Whereas, if they got it wrong in their book, particularly children who are already feeling a little bit, lacking confidence let's say, mathematically. To get something wrong in their book often results in 'Oh, I'm not doing maths.' But if they get it wrong on the screen, okay and they just go back to the drawing board and do it again. And they will do it over and over again. / If it is deleted on the screen and it is not there anymore, it is forgotten. / And you don't write all over it. [LC]

The theme of *Tinkering assisted* focuses on how this provisionality of many ICT results assists forms of tinkering to improve them. The most basic of these forms is

self correction by students, typically following on from a direct check of a result, sometimes made vivid by the technology, occasionally prompted by an evaluative feedback mechanism. Whereas such 'checks' are applied to what are intended as definitive solutions to a given problem, the provisionality of ICT facilitates 'trials' of more tentative solutions, and hence a corresponding shift in strategic logic. The idea of 'trial and improvement' strategies formed part of the national curriculum being followed by these schools, and teachers made reference to the way in which use of ICT supported such strategies. More generally, they pointed to the way in which use of ICT afforded a more experimental approach to tasks (related also to the invisible mistakes sub-theme of Restraints alleviated):

> They are more prepared to have a stab at something and get it wrong because not everyone can see it's wrong and they'll keep trying until they can get it right. [VC]

Arguably, it is awareness of this tinkering style of ICT usage which underpins earlier comments about students 'playing on a computer' or 'playing around on the calculator', under the Ambience enhanced theme.

The theme of *Motivation improved* associates ICT use with the motivation of students towards classroom work. Teachers commented on what students 'love', 'like' and 'enjoy' in relation to using ICT; likewise on what 'motivates them', on what they 'respond well to', and on what they are 'quite taken by'. One further sub-theme suggests that by assisting or permitting students to display -and to be seen to display- greater capability, use of ICT can help build their self-confidence. Across more extended sections of transcript, this idea was associated with the earlier themes of Restraints alleviated and Tinkering assisted:

> I think they can then start to feel more positive about themselves and their work, because often they can just get worse and worse with their untidiness because they know they can't do it so they can't be bothered to try. If they see what ICT can help them do then they might be encouraged to try it a little bit more themselves and then try to improve their own work to that standard. [VC]

The theme of *Engagement intensified* associates ICT use with deeper and stronger student engagement in classroom work. Clearly this theme is closely related to Motivation improved. Teachers noted students being 'more prepared to have a stab', to 'put in more effort', to 'keep trying'. The following quotation draws together many of the ideas associated with this theme -good behaviour, attention to classwork, and a degree of independence and persistence in it:

> They are working more, they're not wasting so much time, they actually do get on with it, the majority of children will get on with it, rather than do one question, turn around and I've got to tell them what to do so they are learning something. [CC]

The theme of *Routine facilitated* associates ICT use with facilitation of relatively routine components of classroom activity, allowing them to be carried out more quickly and reliably, with greater ease, and to higher quality. In this respect, aspects of Routine facilitated underpin some of the phenomena already noted under the

theme of Restraints alleviated, and there was a clear intertwining of these themes in some sections of transcript. What characterises Restraints alleviated, however, is a focus on particular factors inhibiting the participation of persons, whereas Routine facilitated focuses on factors supporting the execution of tasks. The sub-themes of speed and ease were the most prominent. Such use of ICT was seen as particularly important in supporting the more extended project tasks which older students tackled as assessed coursework for the GCSE examination. An example illustrates how use of ICT tools facilitated routine components of such tasks, highlighting the removal of important constraints on the strategies which students could pursue:

> I've just worked this year using draw commands in Word for a bit of coursework called 'Square Moves' where they have to move counters around, and part of the coursework is to show their strategy for moving the counters, and I did it with a low ability group, and we got far better results I feel, because I showed them how to draw circles, and get the sizes right, fill them in different colours, and then once they'd set up the basic grid they could copy and paste the whole grid however many times they wanted, and then they just moved the individual counters around, and as a result of that they did far more work than with the old style of always drawing them out. [TC]

The theme of *Activity effected* associates ICT use with securing and enhancing the pace ('rather than someone poring over a page... they were able to do this in no time') and productivity ('far better results', 'far more work') of classroom activity as a whole. The following quotation illustrates the linkage of Routine facilitated to the pace aspect of Activity effected:

> We've got a graph plotting package which isn't particularly sophisticated... but it makes it nice and easy for the kids to use... Actually drawing a graph and seeing it on the screen, they can very quickly see what's happened to the graph. So using IT in that respect, it makes a significant difference in the depth of understanding and the speed in which it takes to learn skills... You may get there in two lessons rather than three, so you can gain a lesson. [TC]

The theme of *Features accentuated* associates ICT use with the provision of vivid images and striking effects through which features of mathematical constructs -or relations between them- are accentuated:

> The actual immediacy of it and also the fact that it's living, it moves. [VC]

This 'immediacy' of response was one of the important sub-themes to emerge. Likewise the power of 'visual' representations, and the dynamic of actions and their effects:

> So you quickly see what is happening to the gradient and what is happening to the intercept. [LC]

The theme of *Attention raised* associates ICT use with reducing or removing the need for attention to subsidiary tasks, and with avoiding or overcoming related obstacles, so as to better focus students' attention on overarching ideas and processes.

The following quotations bring out the way in which processes already alluded to under the head of Restraints alleviated and Routine effected clear and smooth the way so as to raise and focus students' attention:

> The key thing about the calculators or any ICT applications being able to take away the drudgery out of doing the calculations, so that you can start to access a higher learning point without the problems of making mistakes along the way, clouding the issue. [SC]

The theme of *Ideas established* associates ICT use with the formation and consolidation of ideas through their being 'seen', 'understood', 'accepted' and 'remembered' by students. The following quotation illustrates the association of both Features accentuated and Attention raised with Ideas established:

> When we're using Coypu [graphing package] for shifting curves, and that shows them very easily what altering the equation does to the curve, and that does help them tremendously. / ...It's a very, very difficult topic and so you can just actually get them to draw various curves, and show them what happens when you start altering the equation... Just the immediacy of it, actually means that it hangs together better, because if you see these results and then spend another 15 minutes drawing a graph, the whole thing just feels nothing much, so it's just not better efficiency, but also it is actually sounder for the brain really, if it can see things more immediately. [TC]

CONCLUSION

This study has elicited from practitioners a model of the successful use of ICT to support classroom teaching and learning in mathematics. The model is organised as a system of themes identifying key processes and critical states. Four themes depend most directly on exploiting affordances of ICT: *Ambience enhanced* in changing the general form and feel of classroom activity; *Tinkering assisted* in helping to correct errors and experiment with possibilities in carrying out tasks; *Routine facilitated* in enabling subordinate tasks to be carried out easily, rapidly and reliably; and *Features accentuated* in providing vivid images and striking effects which highlight properties and relations. Three further themes depend in turn on these processes: *Restraints alleviated* in mitigating factors inhibiting student participation such as the laboriousness of tasks, the requirement for -and the demands imposed by- pencil-and-paper presentation, and vulnerability to mistakes being exposed; *Motivation improved* in generating student enjoyment and interest, and building student confidence; and *Attention raised* in creating the conditions for students to focus on overarching issues. Three final themes depend again on preceding processes: *Engagement intensified* in securing the commitment, persistence and initiative of students in classroom activity; *Activity effected* in maintaining the pace and productivity of students within classroom activity; *Ideas established* in supporting the development of student understanding and capability through classroom activity.

This model is intended to serve as a helpful abstraction, providing a generic scheme for conceptualising use of ICT to support classroom teaching and learning in

mathematics. In any actual instance of classroom activity, of course, certain components of the system may assume more prominence than others, and those operative components of the scheme must be filled out more concretely according to the particular circumstances. Nor is the model a deterministic one. Rather it highlights key processes and critical states which require active -and reactive- planning and management on the part of the teacher for ICT use to successfully support teaching and learning. Finally, the model is a tentative one. It is based only on teachers' somewhat decontextualised accounts of successful practice, elicited through group interview; rather than on more strongly contextualised accounts of specific instances of practice, supported by examination of actual classroom events. Nevertheless, earlier variants of this model have already proved their worth in subsequent work with teachers, in helping them to articulate their conceptions of how particular forms of ICT use support teaching and learning.

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