EXPLORING A WORLD OF NUMBER: A CASE STUDY OF THE USE OF CD–ROM IN SCHOOLS

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ABSTRACT

This paper contains a case study of the use of a CD-ROM in a Sheffield secondary school. Nine groups of students tackled a mathematical investigation presented through a video clip on the CD-ROM *The World of Number*. The paper outlines three stages within the process of mathematical investigation and discusses the contribution of the CD-ROM material to each stage of the students' thinking. It concludes that the CD-ROM successfully oriented students by engaging their attention and by illustrating the object of the investigation. The paper argues that *The World of Number* materials are most likely to be used in a self-access setting even if this was not the specific intention of the designers. It discusses ways in which the materials could be made more suitable for self-access work and argues that the role of the teacher is critical within self-access learning. Finally, it is suggested that future CD-ROM materials might contain a mix of expository material, games and additional resources such as text and statistical data.

Why this Study?

The extent to which CD-ROM is being used in UK schools is uncertain. One clue is provided by sales of disc drives to school. The British Educational Suppliers Association (BESA) estimated there were around 74,000 drives in UK schools in May 1995 (BESA, 1995). By sector, this worked out at an average of 5.9 drives per secondary school and 2.2 drives per primary school. CD-ROM technology is far from pervasive but, again according to BESA, the number of drives in school can be expected to double. In addition we can expect growing numbers of school students to have access to CD drives on home computers, a development which will help generate a dramatic growth in CD-ROM tutorial materials for the home.

CD-ROM therefore looks set to play an increasing role in education but one which will be developed on an ad hoc basis as practitioners come to terms with a new technology, with deep implications for both the curriculum and the organisation of learning, with little support and in an atmosphere of developer generated hype. Within this scenario it is almost inevitable that insufficient attention will be paid to the principles on which new programs are designed or to the curricular implications of these programs within specific subject areas. This is a familiar problem. For example the *ImpacT Report* (Watson, 1993) notes the need for an on-going programme of in-service training which would not only show teachers how to use programs but address itself to a "philosophical understanding of the nature of the subject" along with related pedagogical skills and abilities (p. 4). Meanwhile discussions of information technology (IT) within initial teacher education strongly suggest that even when trainee teachers have acquired IT skills for personal use they are not necessarily aware of the potential for using IT in the classroom (see, for example, discussions in Blackmore, 1992; Davis, 1992; Oliver, 1994; and Maddux, 1994).

An exploration of the impact of CD-ROM within specific areas of the curriculum is then a pressing area for research but it is one which is not being fully addressed (though see, for example, Steadman et al, 1992; Coupland & Brown, 1994; Perzylo, 1993; Kanselaar, 1993 as well as related literature on interactive video, for example, Goforth, 1992; Ross, 1991 and, on hypermedia, Jacobs, 1993). More research is needed, but what direction should it take?

Maddux (1993) has characterised the first stage of research into educational computing as one dominated by the notion that exposure to the computer would in itself provide general educational benefits. It is critical that early research into CD-ROM does not parallel this approach by focusing on the technology at the expense of the learner. For example, for the first time user, the most startling feature of CD-ROM technology is the incorporation of video images on the desktop computer. This development offers opportunities for designers to improve the motivational and presentational appeal of their materials (see, for example, Ambron, 1990) but how might this happen? How does video aid learning and in what sense, if at all, is video compelling?

This paper explores the value of one CD-ROM title, *The World of Number,* in the context of self-access learning. Its central concern is to provide a case study of the impact of CD-ROM on learning by exploring materials which are now available and might well become widely used by teachers in UK schools. In this case, the materials are aimed at teachers of secondary mathematics, but the general issues raised at the end of the paper are of wider concern.

The rest of this paper is divided into five sections; a background to the research, a description of the materials, an overview of problem solving in mathematics, the impact of the CD-ROM materials on students' learning and a final section which summarises conclusions from the research.

The Research

The research took place in a local secondary school. In total we worked with nine groups of students from years seven to ten (ages 11-14). Students had volunteered to take part in the research and were of average, or above average, ability in mathematics. They worked in groups of three, organised on a friendship basis. Equal numbers of boys and girls took part; six groups were single sex, three were mixed. We worked with each group for an entire morning or afternoon. This meant students were taken off their normal timetable and that we had to work in the library or other quiet area. Research conditions were artificial but we were modelling what might happen in schools. CD-ROM drives are frequently placed in the library (Steadman et al, 1992) and used by students on a self-access basis. As the interest in CD-ROM shifts from reference materials to subject specific material we would expect more CD-ROM drives to be found in teaching rooms but they might, particularly in mathematics, still be used on a largely self-access basis. We say this because IT developments have a long history of being assimilated into existing teacher routines, see for example Olson (1988) and McCormick (1992), and mathematics teaching is often based around self-access schemes such as the School Mathematics Project or SMILE. (For a discussion of these schemes see Relf, 1992, who describes differentiation as the key issue which they are designed to address.) However, it must be stressed that neither the original interactive video *World of Number* materials, or the CD-ROM equivalents, were specifically designed with self-access in mind, see Phillips et al (1995) and Phillips et al (1994). We are saying this is the most likely way in which they will be used and notice in a recent report on interactive video in schools which considered the *World of Number* materials, that teachers had "expected to be able to leave small groups alone with a system to work in a relatively unsupervised way" (NCET 1995, p. 21).

The focus of our interest was the extent to which these students, who were motivated students working with adults in attendance, could successfully use the materials on a self-access basis. Our role was to observe what went on. Occasionally we were asked a technical question, such as which button on the mouse to press, but we did not intervene in the work of the groups, nor did students ask us to. The discussion in this paper is based on the group conversations (which students gave us permission to record on tape for future reference), our observations of what students were doing at, and away from, the computer and on the notes students made. We also carried out extended semi-structured interviews with each group in which we asked about students' attitudes to mathematics in general, their thoughts on using the materials and about the mathematical ideas contained in the activities. These interviews were recorded, notes made from them and some sections transcribed. Responses to individual questions and themes were then collated and analysed.

Although we asked students to think aloud when they were working on a problem, we were aware this would not provide a full guide to their thinking - students often 'dry up' when they are thinking most deeply (see the discussion in Laurillard, 1993, pp. 48-68). In interviews we found students could recall what they were thinking during an activity in ways which we found consistent and illuminating. This process of recall was often prompted by referring to things students had written, and by reminding them of what they had said.

The value in the case study approach lies in attention to the process of learning and in its 'relatibility'. This is particularly important in the context of multimedia as we are starting from a low threshold of research and at this stage a detailed, probing qualitative approach can highlight some main concerns and map out areas of future potential. In particular here, we wanted to explore the ways in which these materials contributed to learning and to ask what their limitations are and what the implications are for teaching and learning. In doing so, we draw upon the discussion of the materials provided by the developers (Phillips et al, 1994 and l995) and on the previously mentioned major evaluation of interactive media sponsored by the National Council for Educational Technology (NCET, 1995).

The research was carried out by myself with one of two colleagues in attendance. This enabled me to check my understanding of the session with another observer.

The Materials

The *World of Number* is a set of four CD-ROM titles produced by the Shell Centre, University of Nottingham. The materials were originally produced on interactive video format as part of a National Curriculum Council (NCET) initiative, see Phillips et al (1995), and were later transferred to CD-ROM. We used an Acorn version to run on an Archimedes A4000 machine. The pictures were grainy, the sound sometimes became indistinct but overall the technical quality was acceptable to the pupils, though in a packed classroom the problem of sound would be more acute and might require the use of headphones. By contrast, the NCET sponsored evaluation team found that the technical quality of the CD-ROM *World of Number* materials compared badly to the original interactive video materials and this proved a major disappointment to students and teachers who were already familiar with interactive video (see NCET, 1995, p. 45).

We chose to investigate the materials on the *Number Puzzles* disk. These were selected because they were innovative in that they used moving video but were sufficiently self contained and self explanatory so as likely to be widely used by teachers. In fact both Phillips (1995) and Laurillard (1995, p. 50) in their investigations deduced that *Number Puzzles* and the adventure *Who Stole the Decimal Point?* were the two most widely used parts of the original interactive video discs. However we felt that *Who Stole the Decimal Point?* would require greater commitment from the teacher in terms of preparation and innovation in teaching style and wondered if it would be so widely used outside the context of a project

Number Puzzles consists of seven mathematical investigations. By clicking on a play button, the user can see a boy or girl (the children are aged between 11 and 16) who introduces a problem which a group of friends then tackle on screen. The format is based on the television programme *Fun and Games,* see Hoyles (1990), but with the difference that no-one explains a winning strategy at the end. This is a crucial point - the value of the material is limited to the extent it can orient the student; it does not go further than that. In two cases *(Toast* and *Trains)* students can see a solution to the problem, but, as the solution is not explained, in practice these problems are as open-ended as the others. This paper focuses on one particular game *Presents* which all the groups at some stage tackled.

Presents is a game for two players based on the well known game *Nim*. There are fifty parcels on the floor. Each player takes turns to pick up one, two, three, four or five parcels and put them on a wheelbarrow. The winner is the one to pick up the last parcels leaving none left for their opponent. The game is introduced through a video clip which shows the opening moves of the two teams. The scene shifts - there are eight presents left. The two members of one team are debating how many parcels to pick up. They decide to pick up one parcel but they go on to lose the game. The entire clip lasts around two minutes. The clip is supported by a worksheet in which it is suggested that students could try playing the game with twenty counters.

The value of this and other types of mathematical investigation lies in the way in which students are required to develop problem solving strategies. The next section outlines likely steps taken in reaching a solution to the problem.

Tackling the problem

Drawing on Hoyles et al (1991) - but see also Floyd et al (1985) - we identified three stages in playing the game:

1. *Orientation,* in which students grasp the rules of the game and its object and go on to discuss how they would set up their own game.

2. *Specialising,* in which students play the game several times so as to provide data on which to base conclusions.

3. *Generalising,* in which students articulate a strategy for winning the game. We were particularly interested in seeing how far students could take their generalisations. At a simple level (a) they could say that you must win if you leave six parcels for the other player. At a higher level (b) students may see that if you left your opponent 12 parcels you could guarantee to get down to six on your next turn. By a process of iteration, students might then see that the rule is always to leave a multiple of 6 presents. This rule can be stated in general terms (c) as always leave your opponent with a multiple of n + 1 parcels where n is the highest number you can take.

During the activity these stages did, of course, overlap. For example, starting to play the game could be seen both as evidence of successful orientation and the beginning of specialising. The stages were not seen as linear. For example, students would make a generalisation which they would test by playing the game (specialising). As they played they might discard one generalisation and develop a new one. The question we wanted to address was: "What role did the CD-ROM play within the process of investigation?"

The Impact of the CD-ROM

Orientation

Olson (1988) draws the distinction between expressive teaching acts which convey messages about how the teacher wishes to be seen by his or her students and instrumental teaching acts which are directed at learning. This distinction is useful in considering student orientation to the problem.

The expressive power of the video clip lay in the use of young people to present the problem. Students were expected to identify with the personalities on screen and be drawn into the activity. Very largely this worked and the majority of students' comments were favourable:

"I think of adults as being clever and it puts me off. If I see that children can do it we might be able to do it, too." [Katie, Year8]

"It is more interesting... it makes you want to have a go yourself." [Louisa, Year 8]

All the students thought the games had been scripted and that the children were trying to remember their lines. However they did not find the talk too stilted and most realised there would be a lack of clarity if more than one person spoke at the same time as would happen in a more natural setting. Two of the older students felt that the presentation did not work; it was a good idea but did not come over. One of these was critical of the way that young people were called in to give credibility to something which had been designed by adults.

The instrumental role of the film was to introduce the rules of the game and to illustrate that it should be played with physical objects. The concept of the game was not difficult but the demonstration was appreciated by all the groups:

"It's clearer with people ... better than paper. It's different you take it in more." [Kate, Year 7]

"You know what you are expected to achieve. It's easier to understand than reading." [Richard, Year 8]

"It's better to have the picture, it makes it clearer. Writing doesn't always explain it." [Yang, Year 8]

"It gives you a more physical understanding of the problem. On paper you don't feel as if you have much to do with it at all." [Stephen, Year 10]

All the students in our study had used computers at school and the majority of the students had access to home computers of one kind or another. Two had access to a CD-ROM drive at home. All felt confident using computers and felt in control of the materials. This was evidenced in their willingness to pause the video, experiment with the size of the screen and to return to replay the video. They worked co-operatively around the screen and discussed each other's understanding of the film. After seeing the video, all the groups quickly got started on the problem using tiles or counters to represent the presents. A worksheet was available but few looked at it Those who did, rarely referred to it again in the course of the investigation.

Specialising

All groups began by devising different strategic rules for the game and trying them out:

It's something to do with odd numbers; It depends on who goes first; It depends on the number of present you started with; You must take more than the other player; Take two each time; If it's ten left you can win.

However, when it came to testing these hypotheses the students changed the rules of the game so that *both* players had to follow an agreed strategy; for example, both players had to take even numbers of presents. This was clearly unhelpful as they could not tell if they had won by design or by their opponent's poor play. All the groups would have been helped if they could have played the game against the computer. This would have allowed them to test their strategies against an expert and to study the computer's strategy for winning. If they could beat the computer they would have known that they had arrived at a definitive solution. All the groups were aware of this and strongly stated that they wanted the game on screen. As if to compensate, some groups returned to the computer two or three times to view the video of the children playing the game in the hope that from this they could discern a winning strategy. In fact, the on-screen discussion of whether to take one or two presents from the remaining eight could have been a significant pointer to a solution, but students missed this and largely focused on the first moves of the team which started the game. In two other investigations (*Stepping Stones* and *Dressing Table*) students were able to play against the computer and they saw no reason why a game could not be included in *Presents*.

A danger, of course, in playing the computer is that students can become so committed to a trial and error approach that they repeatedly play the game without looking for a generalisation and might even hope to hit on a solution through exhaustion of possibilities; (see the discussion of *Stepping Stones* in NCET, 1995, p.29). We recognise the scenario but we did not find that students who were tackling either the *Stepping Stones* or the *Dressing Table* problems at the computer were put off looking for a generalisation and we felt the advantage of playing against an 'expert' outweighed any potential disadvantage.

Generalising

All the groups were able to reach the generalisation that you won if you left your opponent six presents. This took them between a minimum of 10 and a maximum of 70 minutes to discover. The student within each group who first suggested this 'recipe' for winning-had to defend it and convince the others through playing the game. None of the students could easily explain when they first saw the rule- - it 'came to them' while they were playing or watching others play. There were several instances of students playing to the rule without having articulated it or even apparently being aware of what they were doing - an example, perhaps, of Schon's knowledge in action (1988, pp. 22-40). The articulation of the rule came after the game itself (ie. Schon's reflection in action). On two occasions the opposite occurred. Students articulated the rule to the others but did not use it in the game they were playing. My understanding here was that the students lacked peer support for what they were saying and did not wish to demonstrate the rule if it was going to cause conflict within the group.

All but one of the nine groups decided they had finished the problem when they discovered they could win by leaving six presents for their opponent (rule a). The one group to go further and realise that you should leave a multiple of six presents were a Year 7 group who, interestingly, had taken longest to discover the rule about leaving six in the first place.

In our interviews we wanted to focus every group's attention on further generalisation of the rule they had found. We asked the eight groups who had stopped at rule a if they could say who would win if you left your opponent with seven presents, then eight presents, then nine, and so on. By drawing up a table students quickly realised that the winning strategy was indeed to leave 6, 12, 18 presents, i.e. multiples of six (rule b), and could describe an iterative process to explain why this worked. When asked to suggest a strategy to win if you were allowed to take up to six presents they quickly replied that it would be to leave multiples of seven for your opponent.

It had clearly been within the ability of the groups to go beyond their first generalisation (rule a) and indeed, once prompted, the older students quickly expressed the generalised solution in the format of the formula (rule c).

Clearly then, intervention is a crucial issue. Some intervention was needed to push students beyond what was, for most of them, a trivial solution to the problem. This intervention could have been provided by the children on screen, indeed students could also have been provided with an on-screen solution to the problem. (This is also noted in the NCET report where it is suggested that teachers were disappointed by the "lack of interactivity in general with the *World of Number* materials", NCET, 1995, p.4.) Indeed, the students in our study would have welcomed help and feedback but they all recognised that they would have turned to the hints or to the solution 'too soon'. They understood that the point of doing this kind of investigation was to come up with their own solution for themselves. Two comments illustrated their dilemma:

"It would be cheating to give us the answer, but they should not have left us without one." [Sam, Year 8]

"They shouldn't start by showing us an answer, but you want to know if you are right or wrong... maybe you should be able to look at it after a certain time." [Philip, Year 10]

Several students suggested having video clips of hints or solutions which could only be accessed after a certain time or by entering a secret code passed on by the teacher when the students were 'genuinely stuck'. These are intriguing ideas but not solutions. As we have seen, the time taken to tackle the problem varied hugely; timed access to material would rarely match the pace of the group. In the second suggestion, the level of involvement required of teachers is such that they, and not the computer, might just as well provide the prompt. So where does this leave us?

We would make a further suggestion - that of redesigning the materials to include an exemplar investigation (or investigations) to illustrate strategies in mathematical problem solving. One fairly consistent strategy is to simplify a problem and go about specialising in a systematic fashion so that, for example, the *Presents* problem became clear to the students by starting with seven presents, then eight, then nine and so on. Students seeking help on *Presents* might then refer to a different problem on screen in which they could see this strategy being used. This would, of course, make the problem less open-ended than previously, but it would still require creativity from the students to apply the strategy in a new context.

Including exemplar activities then is not a perfect solution and all kinds of further objections can be made. For example, it would not stop students believing that they had finished the problem after hitting upon the simplest generalisation (rule a) nor could we be sure that the right kind of help was provided when in our study students came up with solutions by themselves and in a variety of ways. In any case, offering help is not the same as giving students the satisfaction of seeing an on-screen solution confirming they had 'got it right'. Nonetheless we believe that future multimedia materials will have to avoid, on the one hand, the step by step 'spoon feeding approach of some self-access mathematics materials and, on the other hand, the absence of help and feedback which is an obvious problem if such materials are to be used in a self-access setting.

In any future scenario the role of the teacher is still critical. The teacher's job is to organise the group; to ensure that both computer based and back up materials are available; to monitor the behaviour within groups; to assess progress and 'proximal development' (Vygotsky, 1978) within a group; to provide encouragement; to prompt students, where appropriate, to work away from the screen or to return to the screen; and to diagnose problems and challenge assumptions. All this needs to be undertaken within the totality of demands made by the class as a whole. In addition, as investigations often provide a suitable context to differentiate by outcome rather than by task, some teachers might also want to introduce exemplar problems of their own to the whole class. In so doing, they might provide a fuller range of teaching styles than in classrooms totally given over to the self-access approach (see Cockcroft, 1982, p. 71).

In examining the role of the teacher within the context of future multimedia materials we are raising some very familiar issues and difficulties. Past experience shows some teachers become overwhelmed by the organisational demands of self-access schemes in mathematics while others can find the time and space to diagnose students progress and pose interesting mathematical challenges (Relf, 1992). Explaining why this happens is an urgent area of inquiry and one of great relevance in considering the introduction of multimedia materials to the curriculum.

Summary

We believe that in our case study video was used successfully to orient students to a problem by engaging their attention and boosting their confidence through vicarious involvement with the youngsters on screen. Further, the video successfully explained the object of the investigation and showed that it was to be tackled using physical objects.

An on-screen game would have been very valuable as was evident from observations and from student comments. This raises an intriguing prospect in that it is quite likely that future CD-ROM materials may contain a rich mix of expository video, games and additional resources such as text and statistical data. Such discs could be described as 'portmanteau' software including, to use Chandler's (1984) classification, hospital, funfair, resource centre and laboratory materials. We predict that developers will take advantage of the storage capacity of CD-ROM to include familiar ideas in a new format. For example, the Nim game has long existed as a SMILE program (SMILE, 1983) and could have been presented on the World of Number disks. This development will be welcomed by some (see, for example, Ball, 1990), but would run counter to the push for using general purpose software in schools, associated in many minds with the introduction of the National Curriculum, (see, for example, Gardner et al, 1993, pp. 9-12).

The study outlines the complexity of the learning process and demonstrates the limitations of the materials in a self-access context, and here we repeat these materials were not specifically designed with self-access in mind. The discs could, we believe, be improved for self-access work by providing exemplar materials for tackling investigations and we note that students did want access to on-screen hints and a suggested solution. If future materials were designed to be more interactive, the role of the teacher is still critical. Some of the issues associated with this role are long familiar from previous innovations within mathematics teaching.

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