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ABSTRACT

The Calculators in Primary Mathematics Project was a long-term investigation into the effects of the introduction of calculators on the learning and teaching of primary mathematics. The Australian project commenced with children who were in kindergarten and grade 1 in 1990, moving up through the schools to grade 4 level by 1993. Children were given their own calculators to use when they wished, while teachers were provided with some systematic professional support. Over 60 teachers and 1,000 children participated in the project. This paper examines the type of classroom activities chosen by teachers. It describes the types of uses of the calculator that have become an established part of new teaching practices. Categories of use were derived from a variety of informal observations and a formal observation schedule used with a random sample of teachers (n=11). Three major functions for the calculator were common: for recording, for counting, and for operating arithmetically on numbers. Contains 16 references. (MKR)

Calculators in Primary Mathematics: An Analysis of Classroom Activities.[1]

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Abstract

The Calculators in Primary Mathematics *project was a long-term investigation into the effects of the introduction of calculators on the learning and teaching of primary mathematics. The project commenced with children who were in kindergarten and grade 1 in 1990, moving up through the schools to grade 4 level by 1993. Children were given their own calculators to use when they wished, while teachers were provided with some systematic professional support. The central purpose of the calculators was to provide children with a rich mathematical environment to explore. Over 60 teachers and 1000 children participated in the project. Research data has been collected on the changes in teachers' expectations and beliefs, changes in the curriculum and on several aspects of the long-term learning outcomes for children.*

In this paper, only the type of classroom activities chosen by teachers are examined. It describes the types of uses of the calculator that have become an established part of the new teaching practices. Categories of use were derived from a variety of informal observations and a formal observation schedule used with a random stratified sample of teachers. Three major functions for the calculator were common: for recording, for counting, for operating arithmetically on numbers. Operating on numbers was the most common function in lessons across all grades. At all grades, about 20% of lesson segments used the calculator for counting. Recording was a common use in the lower grades, but was not important in Grades 3&4. This analysis of classroom activities provides teachers and curriculum developers with information on the role calculators will play when they become firmly embedded in the mathematics curriculum.

Paper presented at the Annual Meeting of the American Educational Research Association New Orleans - April, 1994

[1]This research has been funded by the Australian Research Council, the University of Melbourne and Deakin University. The project team consists of S. Groves, J. Cheeseman, T. Beeby & G. Ferres (Deakin University), R. Welsh, K. Stacey , Y. Williams & C. DiNatale (University of Melbourne) and P. Carlin (Catholic Education Office.)

Introduction

For well over a decade, calculators have been recognised as having the potential to significantly change mathematics curriculum and teaching (Corbitt, 1985; Cockcroft, 1982). While there has been widespread agreement amongst mathematics educators that calculators should be integrated into the core mathematics curriculum (National Council of Teachers of Mathematics, 1980; Cockcroft, 1982; Curriculum Development Centre and Australian Association of Mathematics Teachers, 1987), there is little evidence that such changes are commonly occurring (Reys, 1989).

In the upper secondary school, calculators are now completely accepted as the normal way of carrying out lengthy calculations, having replaced the use of logarithms and tables of functions. For younger children, though, arithmetic is the substance of much of the curriculum and so the place of calculators is still controversial. This is despite the findings of research generally showing positive benefits from the use of calculators along with traditional instruction (see, for example, Hembree & Dessart, 1986). This indicates that widespread change in the use of technology is difficult, demanding that teachers rethink mathematics, mathematics teaching and mathematics learning, as well as develop new and substantially different skills for teaching and assessment (Willis and Kissane, 1989). For teachers of very young children, there is the additional obstacle that good models of appropriate use for calculators are not available. If the view of a calculator is only as a device to do calculations, then its use in the first years of schooling will seem either irrelevant or destructive to children constructing their own knowledge of numbers and operations. This paper will show a broad range of imaginative uses which challenges this view.

Although there have been many calls that calculators should be used in the primary years, very few teachers have actually put this policy into practice. Similarly, there are few studies of calculator use with very young children. In the meta-analysis of Hembree and Dessart (1986), for example, only 6 of the 79 studies analysed involved children in Grades K to 2. One major study of calculator use with primary children was the CAN project in Britain (Shuard, 1992), a qualitative study of the "effect of long-term complete acceptance of calculators in the primary school classroom, from the age of six." (p 34) This project supported teachers as they explored how calculators might best be used and reported on changes in the curriculum implemented in the schools, children's work and changes in their understanding. However there was no well designed quantitative aspect to this project.

The *Calculators in Primary Mathematics* project is a long term investigation into the effects of the introduction of calculators on the learning and teaching of primary mathematics in Australia, with a quantitative as well as qualitative research methodology. It commenced with children who began school in 1989. All children beginning at the six project schools since 1989 have been given their own calculators to use whenever they wish, as in CAN. In 1993, the oldest children were in Grade 4, having used calculators throughout their schooling. Teachers have been provided with on-going professional support to assist them in using calculators to create a rich mathematical environment for children to explore. As in the CAN project the researchers did not supply teachers with ready-made banks of activities to use but encouraged them to share activities that they found successful through the support program of teachers' meetings, classroom visits (approximately once per month) and a newsletter approximately once per term. During 1992, the peak year of classroom support, all 45 Grade K to 3 teachers in six schools were being visited. Interviews with teachers (approximately half an hour each) were conducted with all teachers at the beginning and end of their involvement with the project and at the end of every school year.

This paper reports only one small part of the results of the *Calculators in Primary Mathematics* project. It examines the nature of the classroom activities chosen by the teachers and children and describes the types of activities with the calculator that have become an established part of the new teaching practices. Changes in the modes of calculator use from Kindergarten to Grade 4 will also be described. Other findings from the project which have been reported elsewhere concern learning outcomes for children (Groves, 1992, 1993; Welsh, 1992) and changes in teacher's expectations of children (Groves and Cheeseman, 1993b).

Method

The classroom observation schedule.

During 1990 and 1991, project classrooms were visited by project staff who observed and took part in lessons, interacted with children and talked to school staff individually and in groups about how they were using the calculators in their teaching. These visits were foremost a support mechanism for teachers but also resulted in collection of a large body of anecdotal data, some of which was later published in the newsletter, thereby providing further ideas to support teachers in their incorporation of calculators into the curriculum. Teachers were also requested to complete record sheets of the activities that they had tried, whether successful or not. On average teachers provided one record sheet per month. The activities they reported were collected together into a resource booklet (Williams, 1992).

On the basis of the teachers' record sheets and notes of the lessons that had been observed, a classroom observation schedule was constructed. The schedule was trialled by members of the research team independently coding the same lessons and revised until satisfactory agreement on coding was reached. The observation schedule was designed to record how the calculators were being used in the classroom. Each identifiable lesson segment was coded separately. For example, a lesson might take the following format:
(i) a short warm-up activity using calculators to support oral counting by twos and fours, then
(ii) written work on addition without calculators, then
(iii) children draw animals on a farm and work out the total number of legs, mentally or with calculators and write a related number sentence to explain what they did. These three segments would have been coded separately.

The schedule recorded the incidence of calculator use amongst the children and who initiated the use. However, these are not reported in this paper, which concentrates only on the categories below. The *function of calculator* category describes what was being done on the calculator, whereas the *intended purpose* relates to the mathematical setting in which this was done. Coded as *nature of the activity* is a description of what was going on in the lesson - whether it was a demonstration by the teacher, whether students were sharing what they had found out with the class or a group or a segment where students were working on a set task, when the open-endedness of the set task is recorded.

Function of calculator:

* as a recording device,
* as a counting device,
* for carrying out operations on numbers,
* as an object of exploration
* (not used in this lesson segment)

Intended purpose of calculator use:

* non-mathematical use
* checking answers
* routine calculations
* teaching/reinforcing concepts
* problem solving
* problem solving in a real context
* open investigation

Nature of lesson activity:

* teacher demonstration
* students sharing ideas
* working individually or in groups on
  - free exploration
  - exploration in a structured activity
  - exploration directed by the teacher
  - directed activity only

The formal schedule was used by project staff to record observations of mathematics lessons (generally lasting 45 minutes to one hour) of selected teachers in 1992 and 1993 at monthly intervals. The teachers were randomly selected, subject to obtaining a selection of grade levels and experience in the project. It was requested that the lessons given during the observations should be as normal as possible, so some of the lessons and lesson segments observed did not use calculators. These have not been included in the present analysis.

This paper reports only on a subset of the classroom observations from all teachers from 3 schools during 1992. In this sample of 11 teachers, at least two teachers taught each of the grades K, 1, 2, 3 and 4 (some as composite grades). Four teachers had been with the project since its beginning, and were therefore in their third full year of regular calculator use; four were in their first year. The sample was therefore acceptably representative of the teachers as a whole. A total of 101 lessons by these 11 teachers were observed during 1992.

The use of an observation schedule such as this has a number of intrinsic difficulties. Firstly, there are problems of consistent coding, which were reduced to an acceptable level by the practice sessions referred to above. Secondly, it is not possible to estimate to what extent the lessons observed really did reflect the normal program. Thirdly, the schedule takes no account of the length of the lesson segments observed, their effectiveness or significance in the overall program experienced by the children. Fourthly, some lesson segments have been multiply-classified and hence contribute more than once in an analysis. For all of these reasons, in the analysis that follows only the major trends can be regarded as reliable.

Overall patterns of calculator use

The percentages of lesson segments in each observation category are given in Tables 1, 2 and 3. Lessons in Grade K, 1 and 2 classes are reported separately from lessons in Grade 3 and 4 classes to show changes with age. Table 1 shows that operating on numbers is the most common function for the calculators, rising through the grade levels. Using the calculator for counting remained reasonably constant throughout the grade levels, whereas its use as a recording device stopped, at least in this sample. Table 2 shows that in most lesson segments across the grade levels children worked on tasks individually or in groups on fairly directed tasks. Later analysis will examine whether the amount of direction changed as teachers worked with the project over several years because many teachers commented in interview on a trend towards a more "open" way of teaching. There is a trend for more open-ended lessons in the younger grades. This is evident in Table 2 (higher free exploration and exploring in a structured activity) and in Table 3 (open investigation). In Table 1, we see that younger children more commonly explored the calculator as an object: what it could do and how it could be made to do it.

In Table 3, it can be seen that the calculators were principally used for teaching or re-inforcing concepts. Figure 1a and 1b show the work of two Grade 1 children who had to draw Santa's 8 reindeer and find the total number of legs. They then had to write other number sentences with 32 as the answer. Work like this was common - teachers work on a group of concepts and skills in each lesson. In this case, counting by fours, knowing that addends in sums can be replaced by equivalent addends without altering the total and, for some children, learning about multiplication could all have been part of the teacher's agenda. Problem solving was a common use for calculators, in particular doing calculations beyond the region of comfortable facility for the children in question, as the reindeer task would be for some children. Their use for routine calculation was much less and this will be discussed below, when examples of lessons using the calculator in different ways are given. Teachers did not see the calculator reducing the need for basic skill with number in any way. Checking answers was another infrequent use of the calculator.

Table 1: Percentage of lesson segments[1] showing each category of calculator function.

	Grades K, 1,2	Grades 3&4
Recording	19%	0%
Counting	17%	23%
Operating	54%	75%
Exploring	10%	3%

[1] Owing to multiple classification, some lesson segments are counted more than once.

Table 2: Percentage of lesson segments[2] showing each category of nature of activity

	Grades K, 1,2	Grades 3&4
Teacher demonstration	11%	9%
Students sharing	8%	17%
Students working		
free exploration	4%	0%
structured activity	12%	4%
directed exploring	43%	57%
directed activity only	22%	13%

[2] Owing to multiple classification, some lesson segments are counted more than once.

Table 3: Percentage of lesson segments[3] showing each category of intended purpose of calculator use.

	Grades K, 1,2	Grades 3&4
Routine calculation	7%	19%
Problem Solving	25%	28%
Checking answers	6%	11%
Teaching/re-inforcing concept	46%	39%
Real problem solving	9%	2%
Open investigation	7%	0%

[3] Owing to multiple classification, some lesson segments are counted more than once.

Description of common lesson segments

It is clearly impossible to describe the variety of lessons that have been observed. However, a large proportion of activities can be seen to belong to common lesson "shells", where teachers use the same underlying activity structure and the same mode of calculator use but vary the topic, context or the theme. The intention of the examples below is to illustrate some of the major lesson "shells" that have become widely established in project schools. These basic patterns of calculator use have been observed in many varied forms.

Calculator used for recording.

Young children first see calculators as typewriters that write numbers - when a button is pressed, a number appears on the screen. In all schools, children spontaneously entered their telephone numbers, just as they would type their own names if they played with a typewriter. Since young children have no idea of the world of arithmetic that lies ahead of them, this use of calculators as a recording device is not surprising. However, it was surprising how many different and effective ways that teachers and students found in which the calculator was used for recording. In Grade K, about 25% of lesson segments used the calculator in this way and it remained frequent in lessons up to Grade 2 (about 15%).

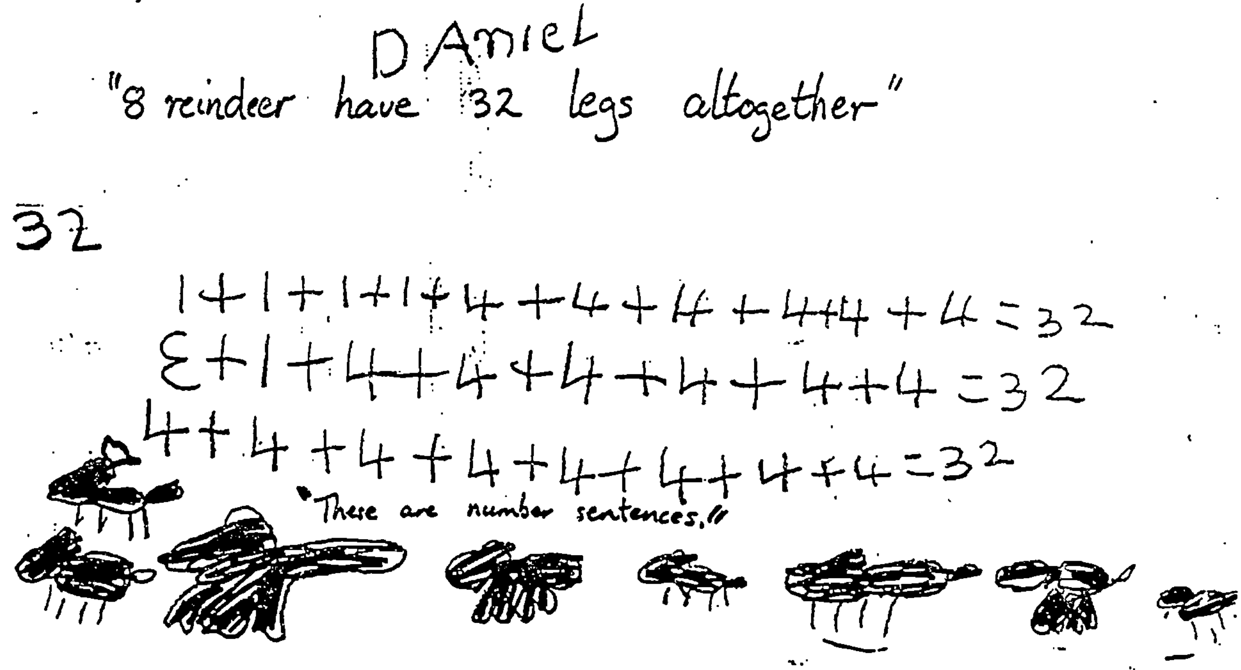
Various number guessing games were played with children keying into the calculator the number to be guessed. The calculator functions only to record the secret number. In some classes children enjoyed entering a number of their own choice into their calculators and then lining up in order of size of the numbers. This game revealed for the teacher the range of numbers with which children felt familiar. Even in Grades K to 2, there were children who felt sufficiently confident with decimals, negative numbers and extremely large numbers to use them in this game. This type of understanding was also evident in the CAN project (Shuard, 1992). The results of written tests from our project which are now being prepared for publication show the extent of this.

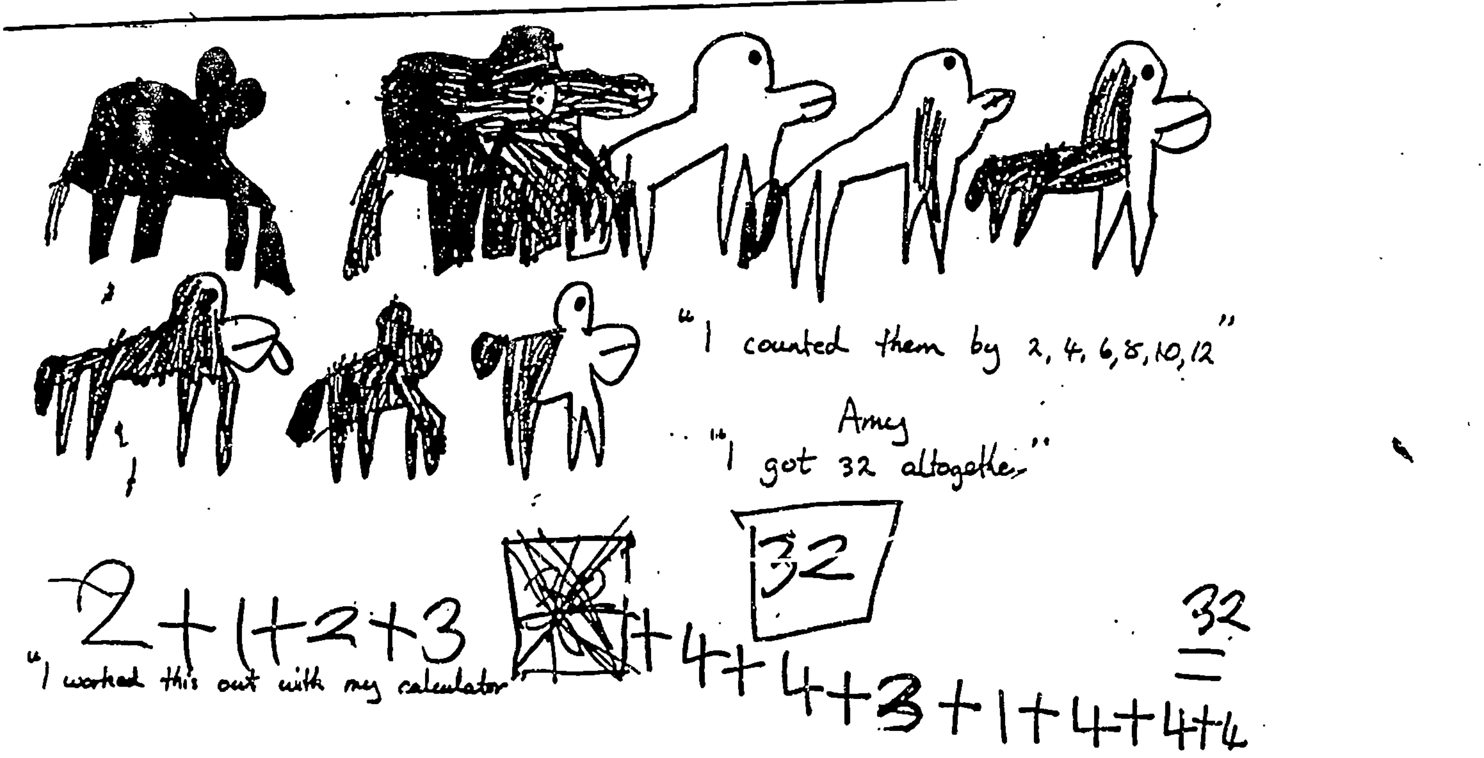
As well as using the calculator for recording numbers, children also used the calculator as a model for recording. Many of the younger children, for example, used it as a reference when confused about which way around to write the numerals 2 and 5 (by knowing that 2 and not 5 is between 1 and 3). More significantly, some teachers were able to use the calculator sequence of button presses to assist children to write number sentences. For example, Ann was using a story about pirates to introduce subtraction and wanted to teach her class to write an appropriate number sentence such as 7 - 5 = 2. Instead, many children were writing only 752. This behaviour is commonly observed in young children's written work (Labinowicz, 1985). It is also observed when children use calculators - they often key in the answer as well as the question - further evidence of the "calculator as typewriter" conception. Ann reported that by using the calculator button presses as a model and stressing the subtraction, children were able to make good progress here. In the written testing of children, we are looking for evidence that the explicit attention to the operation that is required for using a calculator may assist children in identifying operations in word problems.

At the end of 1992, 34 children who had used calculators for all two years of their schooling were randomly selected from all Grade 1 classes in the calculator schools (two boys and two girls for all grades, half as many from composite grades). They were interviewed individually by Connie DiNatale, a graduate student. In these interviews, 85% of children were able to write the number sentence 12 + 7 = 19 corresponding to a flash card showing a group of 12 shells and a group of 7 shells. There were three wrong answers. One was 12 + 7 = 91, a digit reversal error, but the others were 127 = 19 and 12719 indicating residual problems with knowing that operation signs need to be written down.

Figures 1a and 1b: Daniel and Amy's work on reindeers

(This Grade 1 task was to draw Santa's 8 reindeer and to count their legs, write a number sentence to show what you did and then to write other number sentences which show other ways of getting a sum cf 32. The writing in inverted commas was put there by the teacher to record what the child said to her.)





Calculators used for counting.

Most calculators, including the Texas Instrument TI-108 which project schools used, have a constant function: pressing 1, then +, then = produces 2 on the screen and further pressing of = produces 3,4,5,6 etc. Similarly, pressing 5 then + then 2 then = produces 7 and further pressing of = produces the number sequence 9, 11, 13, 15 etc. In this way, the calculator can be used to count up from any number, by any number. It can count down by using - instead of + and also do constant multiplication or division.

This facility is an invaluable support for the development of counting. Table 1 shows that about a fifth of calculator use across the grades is concerned with counting. In many classes, children were able to use the calculator as a prompt when they were serial counting by ones, twos and tens etc both up and down. Many children worked on potentially endless "number rolls" on cash register paper. A segment of the project video (Groves and Cheeseman, 1993a) will illustrate this. Counting down led to the discovery of negative numbers and the development of some facility in counting with them. As noted above, data from written tests, yet to be published, will document the extent of children's understanding in this area.

The counting activities were done in many different ways. In Figure 2a, 2b and 2c are examples of "number pathways". Children specified their own starting numbers (e.g. in Figure 2a, 3) and rule (e.g. in Figure 2a take away 5) and then filled in the squares according to the rule. Successive numbers had to be in neighbouring squares. They could then give their completed pathway squares to other children as puzzles. In Figure 2a, the number pathway goes 3, -2, -7, -12, -17, -22, -27, -32, -37, -42, -47, -52, -57, -62, -67 and then out.

The constant function can also be used as a tallying device. Keying in 1, then + and then pressing = once for each successive event can be used as a paperless way of counting the number of cars passing the school, the number of times you can blink in a minute or the number of paces from the school gate to your classroom. In this way the counting function is supporting the development of sense of number as well as supporting the children while they count, for example over initially difficult passages such as 13, 14, 15, 16 or from 29 to 30. There are many variations of the ways in which the constant function was used to support the development of number sense. Changes in children's number sense have been documented and will be reported elsewhere. Another particularly successful method was for children to count up by tens from zero to a large number (say 290) using the constant function and then count backwards from there to zero by ones. The difference in the number of key strokes required is impressive.

The use of the constant function to support counting and number sense was possibly the most successful aspect of introducing the calculator in the early grades. Despite this, it was not mastered by all children or used (at least in 1992) by all teachers. During the individual interviews mentioned above, Grade 1 children were asked to count aloud to 25 and to show how to do it with the calculator and to count by two's on a bead frame and with the calculator. Whereas all children could count to 25 and 91% were able to count by twos on a beadframe, only 71% and 76% respectively could show how to use the constant function to count with the calculator. The others, who were from only two of the schools, either made no attempt or keyed in the numbers 1, 2, 3, 4, 5, 6, etc in some way. It seems that by 1992, not all teachers had discovered the power of this facility to support early learning, despite the various forms of support offered.

Calculators carrying out operations on numbers

This was the most frequent use of calculators observed in the lesson segments, rising steadily from 39% of lesson segments in Kindergarten to 82% in Grade 4. In the lower grades children used the calculators to carry out calculations beyond the range of numbers that had been dealt with - often adding a lot of little numbers e.g. the number of Easter eggs received by all the children in the class, the total age of everyone in the class. The reindeer work shown in Figures 1a and 1b is a further example of this. Using the calculator to support work in real problem solving (i.e. using mathematical ideas to answer questions that have arisen as part of an investigation for another purpose) was disappointingly infrequent at all levels and especially in the higher grades.

Many routine calculations were embedded in game formats. For example, in Grades 3 and 4, pairs of children play a game with one die. The child who throws the die can add or subtract the number shown from his or her current total. The winner is the first person to reach exactly 21 but not exceed it. This use of the calculator is for routine calculations, particularly as a support for children for children experiencing difficulty with basic number (although it is also a useful recorder).

Many of the uses of the calculator in the "operating on numbers" category were imaginative ways of teaching or reinforcing mathematical concepts. For example, in a lesson on inverse operations, children in Grade 3 used their calculators to make up and check ways of operating on a number and getting back to the starting number (e.g. "choose a number, press +, then 4, then =, then 2 then =, then take away 6 and you will get back to your starting number"). Children in Grade 2 had a lesson on doubling and halving, which began with the teacher posing the question: how do you double a number using a calculator? Children's answers were initially about adding the number on again (e.g. to double 16 you add 16 to itself) but the teacher drew out the possibility of multiplying by 2. When it came to halving the number, many children still wanted to subtract a half (e.g. to find half of 16 on a calculator, you subtract 8), as has been reported before (Feilker, 1986). This lesson combined development of concepts with practice of skills, working out answers with and without calculators.

Only rarely were the calculators used to do or check routine sets of exercises - the teachers still felt that children needed to practice these with pencil and paper alone. Only 7% over all observed lesson segments, including 11% of the Grade 3 & 4 observations, were checking answers. This was a surprisingly low figure.

The real impact of the existence of the calculators on teachers' thinking about the place of algorithms in the school curriculum will be explored in other papers, when the data is fully analysed. However, impressions from interviews with the teachers and discussions at support meetings indicates that only a few teachers really had their thinking challenged on this. They were, for the most part, content to continue to teach algorithms (although perhaps not with the same emphasis as in the past) even though all of the children possessed cheap and reliable machines that could do them faster and better. In this regard it is interesting to note that the CAN project (Shuard, 1992) specifically instructed project teachers not to teach standard written algorithms. We made no such prohibition, hoping instead that it would become a point of debate around which teachers' thinking could develop.

Figures 2a, 2b and 2c: Number pathways showing the variety of numbers children worked with.

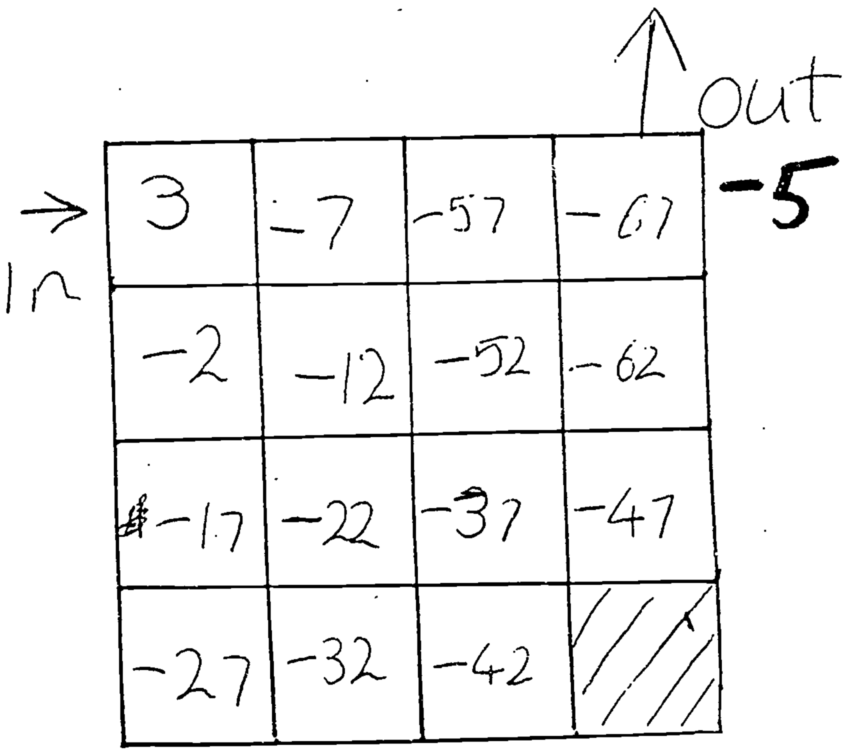


Figure 2a

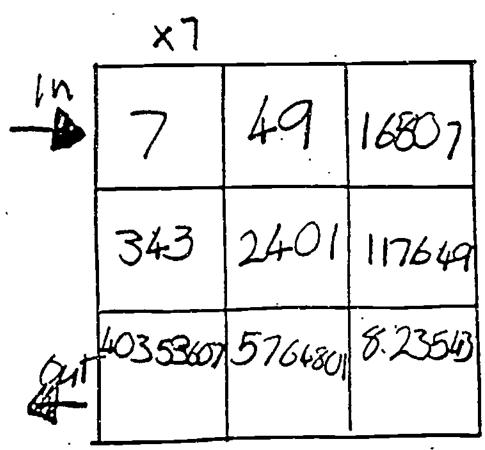


Figure 2b

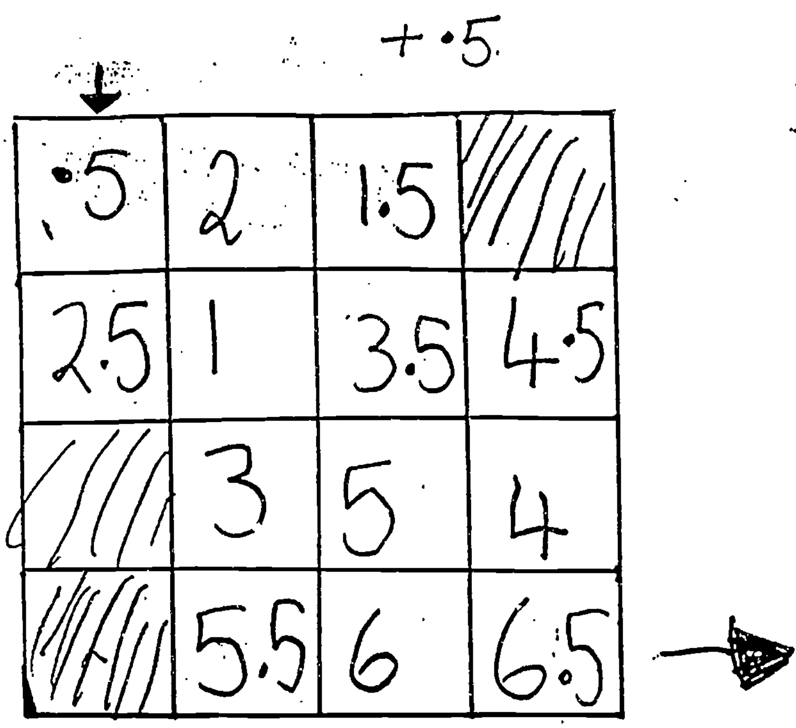


Figure 2c

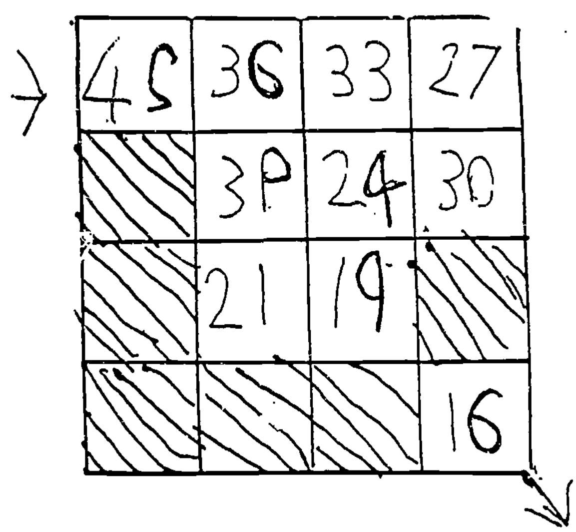


Figure 2d

Calculators as objects of exploration
This category of calculator function was observed in about 10% of lesson segments from Grades K to 2 and about 2% for Grades 3 and 4. These lesson segments often arose when the calculator did something unexpected, such as displaying E when overflow occurred. For example, in one class children were puzzled by E which occasionally appeared on the screen. The project visitor helped them observe that the calculator used E5 to represent 500000000 which does not fit on the screen. Children enjoyed finding out why things like this happened and learning to control the events.

There were also a steady use of non-mathematical uses of the calculator - for example as an object to measure or to measure with (the desk is 10 calculators wide). A few classes investigated properties of the solar cell, such as how long the calculator took to turn itself off when not in use and what happened when no light reached the cell.

Conclusions

The popular and persistent modes of calculator use in the project schools were varied and included for recording alone, for tallying the number of times something occurs, for counting (eg up or down by twos or tens) as well as for calculating within and beyond the range of numbers children can deal with in other ways. The count-on facility of the calculator has been extensively used in the primary years, providing strong support for the development of counting skills, with both positive and negative numbers.

Although there have been many calls that calculators should be used in the primary years, very few teachers have actually put this policy into practice. Interviews with teachers entering our project indicated that a major reason for this was that they had no clear image of how calculators could successfully be used to promote the objectives of a primary mathematics program. This analysis of the activities which teachers have undertaken in the *Calculators in Primary Mathematics* project provides curriculum developers with information on how calculators can be successfully incorporated as a natural and enduring part of the curriculum for young children.

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