DOCUMENT RESUME

ED 373 963 SE 054 523

AUTHOR	Stacey, Kaye; Groves, Susie
TITLE	Calculators in Primary Mathematics.
PUB DATE	Apr 94
NOTE	16p.; For related papers, see SE 054 559-560. Paper presented at the Annual Meeting of the National Council of Teachers of Mathematics (72nd, Indianapolis, IN, April 1994).
PUB TYPE	Speeches/Conference Papers (150) -- Reports - Research/Technical (143)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Arithmetic; *Calculators; Elementary Education; Elementary School Students; Elementary School Teachers; Foreign Countries; Interviews; *Mathematics Instruction; *Mathematics Skills; Number Systems; Observation; Questionnaires; *Teacher Attitudes; Word Problems (Mathematics)
IDENTIFIERS	Australia (Melbourne); *Calculators in Primary Mathematics Project; Mental Computa'ion; *Number Sense

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 gives an overview of the project, with particular emphasis on the ways in which teachers incorporated calculators into their classrooms and the resulting long-term learning outcomes for the students. It first reports on a survey of 700 primary, 7th-, and 8th-grade teachers which established that teachers now support calculator use, even in the first grades, but that actual use falls far behind the support expressed. A brief description is given of the major ways in which the calculator was used in project schools--as a computational device, as a recording device, to count, and as an object to explore. Testing of 3rd- and 4th-grade students (n=225) established that children did understand the number system better after sustained calculator use and that they were better able to choose an appropriate operation in a word problem. A series of interviews showed that calculator use had assisted children to develop number sense and skills of mental computation. Contains 20 references. (MKR)

Calculators In Primary Mathematics

Kaye Stacey
University of Melbourne

Susie Groves
Deakin University – Burwood

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 at kindergarten and grade 1 level in six schools in 1990, moving up through the schools to grade 4 level by 1993. All children in the project were given their own calculator to use whenever they wished, while teachers were provided with systematic professional support. The purpose of introducing calculators was not to make children dependent on calculators, but rather to provide children with a rich mathematical environment to explore. Over 60 teachers and 1000 children participated over the four years of the project. This paper attempts to give an overview of the project, with particular emphasis on the ways in which teachers incorporated calculators into their classrooms and the resulting long-term learning outcomes for the children. It first reports on a survey of 700 teachers from 100 schools, which established that teachers now support calculator use, even in the first grades, but that actual use falls far behind the support expressed. A brief description is given of the major ways in which the calculator was used in project schools – as a computational device, as a recording device, to count and as an object to explore. Four different tools were used to measure long-term learning outcomes for children at grades 3 and 4. Written testing without calculators established that children did understand the number system better after sustained calculator use and that they were better able to choose an appropriate operation in a word problem. There was no detrimental effect on other parts of the mathematics curriculum. A test of calculator use showed how wider knowledge of the number system arising from calculator use significantly assisted children when negative numbers and decimals arose. A task-based interview with a 10% sample of children supported this result. It showed that children with long-term experience of calculators not only performed better overall on the computation items, but also on real world problems amenable to multiplication and division, where their skills in interpreting their answers on calculators, particularly when decimals were involved, led them to perform better than those children without such experience. A second series of interviews showed that calculator use had assisted children to develop "number sense" and skills of mental computation.*

Paper presented at the
Research Presession of the 72nd Annual Meeting of the
National Council of Teachers of Mathematics
Indianapolis – April 1994

* The *Calculators in Primary Mathematics* project was funded by the Australian Research Council, Deakin University and the University of Melbourne. The project team consisted of Susie Groves, Jill Cheeseman, Terry Beeby, Graham Ferres (Deakin University); Ron Welsh, Kaye Stacey (Melbourne University); and Paul Carlin (Catholic Education Office).

Calculators In Primary Mathematics

Kaye Stacey
University of Melbourne

Susie Groves
Deakin University

Introduction

For well over a decade, calculators have been recognised as having the potential to profoundly change the curriculum and the nature of mathematics teaching, with widespread agreement amongst mathematics educators that calculators should be integrated into the core mathematics curriculum (National Council of Teachers of Mathematics, 1980, p.9; Cockcroft, 1982, p.109; Curriculum Development Centre and The Australian Association of Mathematics Teachers, 1987).

In Britain, the *Calculator-Aware Number* project (CAN), which commenced in 1986, began to explore what a curriculum might look like if it takes seriously the implications of calculator technology. The CAN project found that children developed a wide range of strategies for carrying out calculations and, in general, reached a high level of numeracy for their age (Duffin, 1989; Shuard, Walsh, Goodwin & Worcester, 1991).

The question of the role of formal paper-and-pencil algorithms and the balance of emphasis placed on mental, paper-and-pencil and calculator computations is of critical importance in mathematics teaching at this time. Of the three available methods of computation, mental and calculator computations are the ones typically used in everyday life. However, paper-and-pencil methods still receive the most emphasis in schools. The emergence of calculators and computers serves to highlight the lack of congruence between school mathematics and real mathematics (Willis & Kissane, 1989, p.58).

Recently, powerful attempts have been made to change this situation in Australia. The *National Statement on Mathematics for Australian Schools* (Australian Education Council, 1990) endorses the 1987 national policy on calculator use, recommending that all students use calculators at all year levels (K-12) and that calculators be used both as instructional aids and as learning tools. In line with world-wide trends, the national statement has an increased emphasis on developing number sense through mental computation, partly in recognition of the role of the calculator.

Nevertheless, widespread change in the use of technology has not come about because it is no trivial matter to bring about such change: teachers need to rethink mathematics, mathematics teaching and mathematics learning, as well as develop new and substantially different skills for teaching and assessment.

The Calculators in Primary Mathematics *project*

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 was based on a model of teacher change which assumes that the major motivation for teachers to change is the desire for improvement in student learning outcomes and that changes in teachers' classroom practice need to precede changes in teachers' beliefs and attitudes (Guskey, 1986, p.7-10).

The project commenced at kindergarten and grade 1 level in six schools in 1990, with 45 kindergarten to grade 3 classes participating in 1992 and 33 grades 2 to 4 classes participating in 1993. Over 60 teachers and 1000 children participated over the four years of the project.

Children were introduced to calculators on entry to school (i.e. at age 4 or 5) with all children involved having access to "their own" Texas Instruments TI-108 calculator in class. The purpose of introducing calculators was not to make children dependent on calculators, but rather to provide children with a rich mathematical environment to explore.

The project did not supply teachers with activities or a program to follow. Instead, teachers were encouraged to share the activities they devised through regular school and network meetings and a regular project newsletter. Unlike the CAN project, teachers were not specifically asked to refrain from teaching standard written algorithms.

The project was designed as a long-term investigation which sought to:

- document the extent to which teachers incorporated calculators into their teaching and the ways in which calculators were used;
- ascertain whether teachers' expectations of children's mathematical performance changed as a result of the introduction of calculators and what long-term effect this had on the curriculum;
- determine the long-term learning outcomes for children involved in the project; and
- explore changes in teachers' beliefs and practice in regard to the learning and teaching of mathematics.

Data was collected through regular classroom observations, teacher interviews, written teacher evaluation sheets and questionnaires, as well as large scale written testing and interviewing of children at grade 3 and 4 levels. A large scale survey of teachers was also undertaken to determine attitudes and practice related to calculator use in the wider community.

This paper attempts to provide an overview of the project, with particular emphasis on the ways in which teachers incorporated calculators into their classrooms and the resulting long-term learning outcomes for the children.

Using calculators with young children: attitudes and practice

In 1990, a survey of 700 primary classroom teachers and year 7 and 8 mathematics teachers at 100 Melbourne schools was conducted to determine attitudes towards calculator use and the extent and purpose of current calculator use in the wider school community. Results indicated a remarkable shift in favour of the early introduction of calculators since a similar survey was carried out ten years earlier (Ferres, 1981). In the 1990 survey, 75% of teachers supported calculator use in kindergarten to grade 3, compared with a mere 7% in 1980. These attitudes, however, did not necessarily translate into practice, as 58% of K – 3 teachers admitted to rarely or never using calculators in their classrooms.

It might be hypothesised that the main reason for such a low rate of calculator use is their lack of availability. However, at a time when most primary classrooms in Australia boast a computer costing approximately ten times the price of a class set of calculators, any lack of availability of calculators in K – 3 classrooms must reflect the priority attached to their use, rather than mere cost. Hence lack of availability cannot be seen as the major cause for the mismatch between attitudes and practice.

The introduction of calculators to young children requires a realisation by teachers that their use is not restricted to "number crunching" and an awareness of how other uses might be incorporated into their mathematics programs. It is significant that while teachers in 1990 expressed a high level of support for "creative" uses of calculators, this was not matched by their teaching practice. The gap was particularly evident for K – 3 teachers. For example, over 80% of teachers at all year levels supported the use of calculators to allow for more challenging problems solving situations and also to develop new concepts and skills. Yet in both instances, 60% of K – 3 teachers admitted to rarely or never using calculators for these purposes.

Therefore, a first step towards realising the full potential of the calculator in K – 3 classrooms is a demonstration of ways in which it can be used for other purposes than mere computation.

Using calculators in the classroom

During 1990 and 1991, a large body of anecdotal data was collected through an extensive program of classroom visits by project staff and teacher self-reporting of activities. In four of the schools, each teacher was visited once a fortnight on average, while teachers completed about one record sheet per month. In the remaining two schools, visits by project staff did not include classroom observations. Some of the activities teachers reported were collected together into a resource booklet (Williams, 1992), copies of which were distributed to the schools for the information of new (and old) project teachers.

Four major ways of using the calculator emerged. These are described and illustrated by means of examples below.

The calculator as a recording device

Young children spontaneously used their calculators as a "scratch pad" to record their telephone numbers, their scores when playing games, interesting patterns and even the date. Writing numerals can be a time-consuming and onerous task for young children, so calculators provide the opportunity to record (often very large) numbers easily and change them at will.

Teachers have exploited this spontaneous use by devising many activities which, in fact, make no other use of the calculator than simply as a recording device.

For example, a grade 1 and 2 teacher devised an ordering activity, *number line-up,* which involved a small group of children entering numbers of their choice into their calculators and then ordering themselves according to the numbers on their calculator displays. More and more children were added to the "line-up", with each new child needing to find their correct position. Children frequently included negative or very large numbers in this activity and exhibited a quite sophisticated knowledge of the number system.

The teacher who devised this activity has used it, and other similar activities, over and over again. She commented that the activities she now tries to use are ones where the children can "take themselves where they want to go" and that she is never sure what is going to happen. She identified this as a major change in her own teaching of mathematics and believes that she uses many more open-ended activities than in the past.

The calculator as a counting device

One of the most effective uses of the calculator with young children is as a counting device. The built-in constant function on the calculator allows counting by any chosen number, from any desired starting point. By watching the display, children can match the numerals to the words for small numbers; see what number comes before or after any given number; learn about place value; and make discoveries such as how to count by odd numbers on their calculator, or how to count backwards.

One kindergarten teacher initiated an activity, which she called *number rolls*, which became popular with many project teachers. Long strips of paper were used to vertically record counting on by a constant. Many children began by counting by 1's and continued to do so. Others, however, moved on to counting by numbers such as 5, 10 or 100. At least one child observed that counting by 9's usually leads to the units digit decreasing by one each time, while the tens digit increases by one. This activity continued for a long period of time. In the classroom where it started, just as the teacher was ready to abandon the activity, she noticed that many children were beginning to make conscious predictions about the next number in their sequence - even when they could not necessarily read the numbers aloud. Many children counted into the thousands and tens of thousands, while others counted backwards. Other teachers have used this activity with their classes since it was first reported.

In another kindergarten class, where children had been discussing and drawing "What lives underground?", Alistair said "Minus means you are going underground". When questioned what would be the first number above the ground, he said "zero". In yet another kindergarten grade, Ben had counted up to 17 900 by 100's on his number roll. When asked what number would be reached after pressing equals two more times, he wrote 18 100, although he read it as eighteen hundred and one.

For many teachers one of the frightening aspects of calculator use is the possibility that children may encounter very large numbers, negative numbers and decimals "before they are ready". Project teachers who have now become comfortable with calculators in their classroom take the opposite view. They see their previous curriculum constraints as imposing artificial boundaries on the children. Because they are no longer so worried about children finding out things they won't understand, they now regard constraints on the type and sizes of numbers used as "stupid".

The calculator as a computational tool

Calculators are frequently used as a computational tool in order to solve real-life problems (where the size of the numbers would otherwise be prohibitive) or to carry out numerical investigations. An example of how the presence of the calculator allows children to work with larger numbers and solve more realistic problems was the *tree survey* carried out by grade 1 and 2 children, who worked in groups to tally the number of small, medium and large trees in the large, heavily treed school ground. Children used several different methods to count the trees, including tallying with paper and pencil and counting with their calculators. The calculator allowed the totals (up to a hundred for each category) to be found. Groups obtained different answers, which led to a lengthy class discussion about which numbers to use when representing the results in graphical form. Children made considerable progress towards developing an understanding of quite sophisticated statistical concepts.

In another activity, kindergarten children sorted the teddy bears they had brought to school according to colour and counted how many teddy bears there were altogether - some counted aloud by ones, some by twos, others used the constant function on their calculators, while a few used the calculator to find $7 + 4 + 3 + 4 = 18$. When they went back to their tables to record what they had done, some children drew bears, others wrote number sentences, while many struggled to accurately record what they had done. Byron immediately wrote the number sentence shown above and then proceeded to find as many ways as he could to get 18 on his calculator as the sum of other numbers – e.g. 9 + 1 + 8 and, even more remarkably, 6 + 6 + 6. Although the calculator was performing the actual additions for him, he needed to predict which numbers would lead to a sum of 18 and only used the calculator to confirm or contradict his predictions.

The calculator as an object to explore

The calculator was also being used as an object of discovery in its own right. Children at all levels were keen to discover the functions of the various keys and to establish for themselves that the + key, for example, has the effect of determining "how many altogether". Individual children who discovered how to use certain functions, such as the memory, quickly passed on the information to others who were interested, which was by no means the whole class. Children were fascinated to find out how to switch off their solar-powered calculators – many kindergarten children tried to see what happened to the display when they put the calculator under their sweatshirts. A grade 2 and 3 class accidentally discovered that the calculator switches itself off when not in use. They turned this into a maths / science experiment to find out how long this takes. Children devised methods for accurate timing, discussed how many trials would be needed for a sufficient degree of accuracy, and found ways to calculate a rough average of the different trials.

For further details of classroom activities and the role of the calculator, see Stacey (1994); Groves, Cheeseman, Clarke and Hawkes (1991); Groves, Ferres, Bergfeld and Salter (1990) and the videotape *Young Children Using Calculators* (Groves & Cheeseman, 1993).

The classroom observation schedule

On the basis of the teachers' record sheets and notes of the lessons which had been observed during 1990 and 1991, a classroom observation schedule was constructed. The observation schedule allowed lesson segments to be coded according to a number of criteria, including the way in which the calculator was being used (i.e. as a recording device, a counting device, a computational tool, an object to explore, or not used at all in the lesson segment observed). The intended purpose for using the calculator (i.e. non-mathematical use, checking answers, routine calculations, teaching or reinforcing concepts, problem solving, problem solving in a real context, and open investigation) formed another coding category.

The formal schedule was used by project staff in 1992 and 1993 to record, at monthly intervals, observations of mathematics lessons of selected teachers. The teachers were randomly selected, subject to obtaining a spread of grade levels and experience in the project.

Stacey (1994) analysed a total of 101 lessons taught by 11 teachers who were observed at three of the schools during 1992. Among other results, she found that the incidence of using the calculator for counting remained reasonably constant throughout the grade levels, whereas its use as a recording device stopped by grade 3 and 4 (see Table 1).

Teachers and children used calculators as a recording device in many different and effective ways. At the kindergarten level, about 25% of lesson segments used the calculator as a recording device, and it remained a frequent use in lessons up to grade 2 (about 15%).

Using calculators as an object to explore was observed in about 10% of lesson segments from kindergarten to grade 2, but only in about 3% for grades 3 and 4. These lesson segments often arose when the calculator did something unexpected, such as displaying E when overflow occurred. Children enjoyed finding out why things like this happened and learning to control the events.

Table 1
Percentages of Lesson Segments Coded According to Each Category of Calculator Function

	Grade levels	
Calculator Function	K, 1 & 2 *	3 & 4 *
Recording device	19	0
Counting device	17	23
Computational tool	54	75
Object to explore	10	3

* Figures indicate percentages of segments where calculators were actually used.
Owing to multiple classifications, some lesson segments are counted more than once.

Using calculators as a computational tool 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.

Many of the lesson segments categorised as using calculators as a computational tool employed imaginative ways of teaching or reinforcing mathematical concepts. For example, in a lesson on inverse operations, children in grade 3 used their calculators to devise and check sequences of operations which result in returning 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".

Only rarely were calculators used to check answers, with 7% of all observed lesson segments, including 11% of the grade 3 and 4 observations, falling into this category (see Table 2).

Table 2
Percentages of Lesson Segments Coded According to Each Category of Intended Purpose of Calculator Use

	Grade levels	
Calculator Function	K, 1 & 2 *	3 & 4 *
Checking answers	6	11
Routine calculations	7	19
Teaching/reinforcing concepts	46	39
Problem solving	25	28
Problem solving in a real context	9	2
Open investigation	7	0

* Figures indicate percentages of segments where calculators were actually used.
Owing to multiple classifications, some lesson segments are counted more than once.

At the grade 3 and 4 level, checking answers and routine calculations only accounted for 30% of all observed lesson segments, with problem solving accounting for another 30% and teaching or reinforcing concepts close to 40%. An even lower incidence of use for checking answers and routine calculations was recorded in kindergarten to grade 2. This is a heartening result in view of the survey results reported earlier, which showed that, while teachers supported non-routine uses of calculators, the majority rarely or never used them in this way.

Long-term learning outcomes

Four different tools – a written test, a test of calculator use and two different interviews – were used over the three year period 1991 to 1993 at grade 3 and 4 levels to determine the long-term effect of calculator use on children's learning of number.

All grade 3 and 4 children were given the written test and the test of calculator use, in each of the years 1991, 1992 and 1993. A stratified random sample of 10% of these children also took part in one of two 25-minute interviews in 1991 and 1992, with two distinct stratified random samples of 10% each taking part in each of the interviews in 1993 (see Table 3).

The 1991 children, together with the 1992 grade 4 children (none of whom had been part of the calculator project and could therefore be assumed to have had minimal exposure to calculators) formed the control group for the study. At the time of testing, the 1992 grade 3 children and all of the 1993 children had been part of the project for $2^1/_2$ and $3^1/_2$ years respectively.

Table 3
Numbers of Children Involved in the Interview and Testing Program

	Year					
	1991		1992		1993	
Grade	3	4	3	4	3	4
Years in project	0	0	2.5	0	3.5	3.5
Written test*	225	225	250	250	275	275
Calculator use test *	225	225	250	250	275	275
Interview 1*	28	28	28	0	30	30
Interview 2*	0	0	0	27	31	27

* Figures indicate (approximate) numbers of children tested or interviewed

Data analysis is nearing completion. A summary of findings based on the results of the various testing instruments is given below.

The written test

The written test was designed to test children's understanding of the number system; their performance on non-calculator items related to basic numeracy, such as reading train time-tables; knowledge of number facts; routine paper-and-pencil computations; and their choice of operations for word problems.

At the time of devising the test, the hypotheses were that a comparison of results for children with long-term experience of calculators and those without such experience would show:

- increased understanding of the number system and improved choice of operations in word problems;
- no decline in numeracy, knowledge of number facts, or routine paper-and-pencil computations.

The hypothesis that children using calculators frequently would be better able to identify an appropriate operation in a word problem was developed because of the very explicit way in which children must choose which of the operation buttons to press when using the calc 'lator. In mental arithmetic, children can often work out answers without consciously knowing which operation they have used, or by actually applying a different operation (e.g.subtraction can be performed mentally by adding on).

Because of the large number of items which were considered necessary to be sampled and the large number of children being tested, 6 different written tests were devised – 3 for grade 3 and 3 for grade 4 – with some overlapping parts and items.

The tests were done during normal class time and took approximately 30 minutes to complete. In each class, tests at the appropriate grade level were randomly allocated to students, with as close as possible to equal numbers of each of the three tests being used.

Table 4 lists a selection of items from each of the parts of the written test.

Table 4
Selected Items from theWritten Test

Part	Sample Grade 3 Items	Sample Grade 4 Items
A. Understanding of the number system	Write in figures: ten more than 7095	Finish this counting pattern: ..., ..., 0.7, 0.8, 0.9, ...
B. Numeracy	Pat is eight years old. Put a circle around the best guess for her weight. a) 30 grams b) 3 kilograms c) 30 kilograms d) 300 kilograms	Mum saves 50c coins. She has collected 85 coins so far. How much money has she saved?
C1. Knowledge of number facts*	20 – 1 = 9 x 3 =	20 + 4 = 8 + 5 =
C2. Routine paper-and-pencil computations	35 + 29 (vertical) 203 x 3 (vertical)	75 – 28 (vertical) 928 + 4 =
D. Choice of operations for word problems#	I have 132 flowers to plant in the garden. I want to plant them in 12 equal rows. How do you work out the number of flowers in each row? a) 132 + 12 b) 132 x 12 c) 132 – 12 d) 132 + 12 e) 12 – 1	The Easter Bunny left 75 eggs at our house. We ate 25 eggs straight away. How do you work out the number of Easter eggs we had left? a) 75 + 25 b) 75 x 25 c) 75 – 25 d) 39 + 11 e) 75 + 25

* All six tests used the same items for this part
\# Grades 3 and 4 tests used the same items for this part

The fact that three different tests, of slightly differing levels of difficulty, were used at each grade level presented some problems with the analysis. In this paper we present the results of an analysis where the population was considered to be schools and the statistical analysis was a paired t-test carried out at each grade level on the six pairs of scores for each of the five parts of the written test. For each part, the score for each grade level at each school was constructed by taking the mean of the mean scores on that part for each of the three tests. For each school, at each grade level, this gave a score for each of the five parts – these then became the raw scores for the analysis.

Table 5
Comparison of Results by Part of Written Test for Children With and Without Long-term Calculator Experience

	Grade 3				Grade 4			
	1991		1993		1991 & 1992		1993	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A. Understanding of the number system	7.17	1.50	7.71	0.64	7.98#	1.14	8.52#	1.10
B. Numeracy	2.32	0.36	2.35	0.33	1.81	0.21	1.70	0.19
C1. Knowledge of number facts	7.32	1.00	7.32	0.48	8.32	0.41	8.35	0.27
C2. Routine paper-and-pencil computations	2.85	0.86	3.01	0.43	3.69	0.89	3.55	0.66
D. Choice of operations for word problems	1.16*	0.50	1.44*	0.36	1.93	0.31	1.95	0.23

Significant difference between 1993 and 1991 & 2 at $p \leq 0.05$ level (df = 5, t = 2.333)

* Significant difference between 1993 and 1991 at $p \leq 0.05$ level (df = 5, t = 2.082)

Table 5 shows the means and the standard deviations of these raw scores for each part of the tests at grade 3 and 4 level and the results of the paired t-tests. The comparison used was long-term calculator experience (defined here as $3^1/_2$ years in the project) against no experience (defined here as 0 years in the project). Hence the grade 3 results are a comparison or 1991 children with 1993 children, while the grade 4 results compare 1991 & 1992 children with the 1993 children.

An analysis of significance and direction of the changes for each part of the written test reveals the following general conclusions taken over the two grade levels:

- understanding of the number system improved (as hypothesised);
- there was no change in numeracy not related to number (as hypothesised);
- there was no change in knowledge of number facts and no change in computational ability (as hypothesised);
- there was an improvement in ability to choose an appropriate operation for word problems (as hypothesised) but only at grade 3.

Although the differences when analysed in this way are not statistically very strong with only six data points, they support the original hypotheses of the effect of calculator use. The small declines in performance in some areas by the grade 4's are not a cause of concern.

The calculator use test

The written tests described above were done by children without using calculators. However, it is also of interest to compare children's ability to use a calculator to solve problems. A further short written test, which was done by all grade 3 and 4 children in 1991, 1992 and 1993, was used to measure this. The first eleven items were direct calculations (such as 396 ÷ 11 = ; 2458 + 2542 = ; and 49 − 68 =). Items 12 and 13 involved money problems which required children to interpret the decimal point for dollars and cents in both input and output. In Item 14 (see Figure

1 below) children were also asked which operation keys they had used. This last item was intended to detect whether children had become more sophisticated in being able to see that multiplication rather than addition could be chosen as the operation.

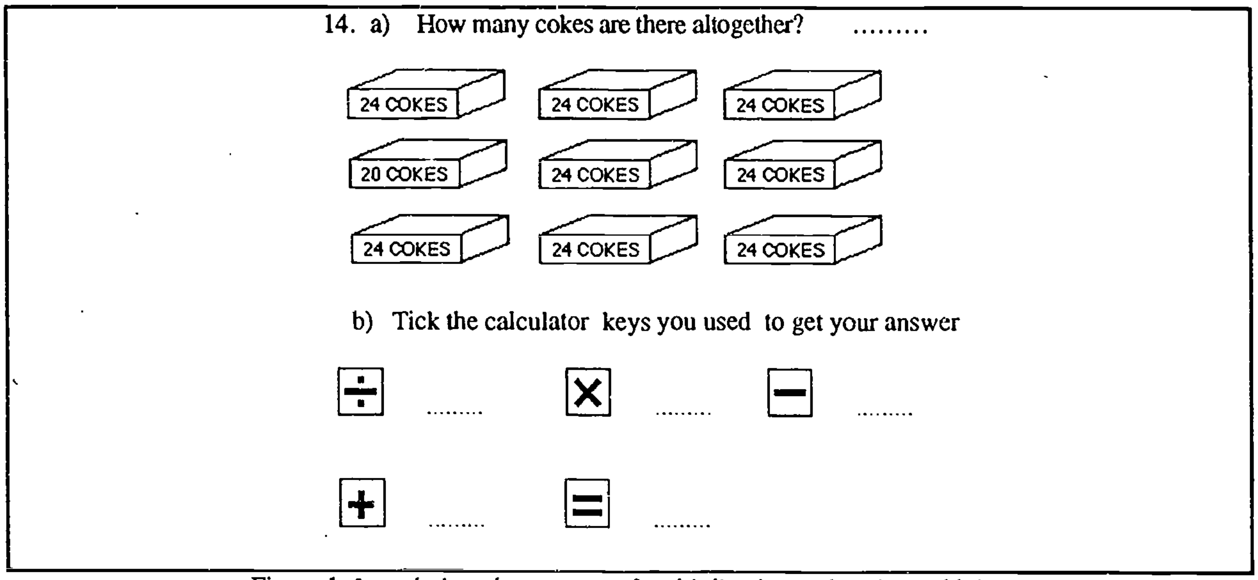

Figure 1. *Item designed to test use of multiplication rather than addition*

The analysis reported here compares the performance of grades 3 and 4 children who had been in the calculator project classes for at least three years with those who had been in the project at most six months. The number of children tested in each category is given in Table 6. Because of general increases in the size of the six schools over time, the sample with three or more years calculator experience contains a markedly greater proportion of the younger grade 3 children than does the sample without such experience (45.9% compared to 37.0%). This means that the results will tend to understate the improvement due to calculator experience. The results are not reported separately for grades 3 and 4 because they are follow a similar pattern, with performance at grade 3 level a little below grade 4 in all instances.

Table 6
Numbers of Children for Calculator Use Test by Grade Level and Years of Experience

	≤ 6 months experience	≥ 3 years experience
Grade 3	221	159
Grade 4	376	188
Total	597	347

Seven items involved only positive integers (e.g. 186 + 492 ; 1 000 000 − 192 ; and 396 ÷ [illegible]1). Children needed to enter the digits and operations signs into the calculator and correctly record the answer. The questions were well done by both groups. The percentage of correct answers depended on the number of steps involved (from 95% correct for questions involving few steps to 75% for a question involving many steps). It is clear that children need only minimal exposure to calculators to be able to use them in this way. The errors in these questions were simple transcription errors and their incidence was not affected by the amount of practice the students had at school.

By contrast, the calculator group showed markedly better performance on items which involved negative numbers and decimals. For example, 67% of the calculator group and 51% of the non-calculator group were able to correctly answer the question 1833 + 65 (which results in a decimal answer) while for the question 49 – 68 the corresponding figures were 77% and 61%. For all items involving negative numbers and decimals, the difference in the proportion of students getting correct answers was statistically strongly significant. These results support the conclusions drawn from other quantitative and qualitative data that using calculators regularly enhances children's familiarity with a wider range of numbers.

The final item asked children to work out the number of bottles of soft drink in ten crates, nine of which held 24 bottles and one one of which held only 20 bottles (see Figure 1). This question could be solved by addition of 10 numbers or by taking a shortcut with multiplication (e.g. 24 x 9 – 4 or 24 x 8 + 20). As discussed above, it was one of the hypotheses of the project that long-term use of calculators would help children identify operations more clearly, so it was predicted that more children would realise that multiplication could be used here instead of repeated addition. Of the 597 children without calculator experience, 53% (317 children) had the correct answer. Of these, 22% had used multiplication. For the 347 children with calculator experience, 60% (209 children) had the correct answer, with 30% having used multiplication. A chi-squared test found this difference to be significant at the $p \leq 0.05$ level. This adds further evidence to the claim that students with calculator experience were more able to identify a relevant operation.

Interview 1

The first interview focused on aspects of children's understanding of the number system; their choice of calculating device, for a wide range of numerical questions; and their ability to solve "real world" problems amenable to multiplication and division, with or without calculators. Throughout the interview, children were free to use whatever calculating devices they chose. Unifix cubes and multi-base arithmetic (MAB) blocks were provided as well as paper-and-pencil and calculators. Many of the questions were expected to be answered mentally.

Welsh (1992) analysed the choice of calculating device used by the control group of (non-calculator) grade 3 and 4 children in 1991 on the 24 computation items – which ranged from simple additions such as 7 + 5 and 20 + 30 to division items such as 15 ÷ 4 and 2 ÷ 40 , as well as including money items such as 7 x $3.53 . Results indicated that, wherever possible, children used mental computation (including automatic response and fingers) in preference to calculators, with little or no attempt to use written methods or materials.

Groves (submitted) compared the performance of the 1993 grade 3 and 4 children with that of the 1991 control group on these same items. Children with long-term experience of calculators performed significantly better overall on the computation items, with an item by item analysis revealing significantly better performance on the five items requiring a knowledge of place value for large numbers (62750 + 50), subtraction with a negative answer (3 – 7), division with a remainder (15 ÷ 4), and multiplication and division of money (7 x $3.53 and $153 ÷ 4). These children also made more appropriate choices of calculating device and were better able to interpret their answers when using calculators, particularly where decimal answers were involved. In particular, the only two items which showed a significantly different pattern of choice of calculating device ($153 ÷ 4 , 3 – 7) were also amongst those for which the 1993 children performed significantly better than the 1991 control group. The first of these items is one where calculators would appear to be the most reasonable choice of device for many grade 3 and 4 children. It is also an item where the use of a calculator is far from straightforward – in order to obtain a correct answer it is necessary for children to be able to interpret the calculator display correctly. While 27 children attempted this item using a calculator in 1991, only 16 of these obtained a correct answer, compared to 41 correct answers from the 44 children using a calculator in 1993. Examination of the data confirms that it was not inability to accurately key in the numbers which caused the errors in 1991, since every incorrect answer using calculators was due to inability to correctly read the display.

In the first two parts of the "real world" problem amenable to division, children were presented with clear bottles containing the appropriate number of white, medicine-like tablets (actually sweets). The bottles were attractively labelled with the contents and the amount to be taken each day – for example, "15 tablets take 3 each day", as well as the distracter "$7.43". For the remaining three parts, accurate volumes of coloured liquid were used with information such as "120 ml take 20 ml each day" and a price. For this example (the first using liquid "medicine"), 20 ml was poured from the bottle into a clear medicine measure. In each case, children were asked how many days the medicine would last. In the multiplication problem, children were shown a paper clip chain, consisting of 17 multi-coloured clips, which they were told was made by a grade 3 child at another school. They were then asked how many paper clips would be needed if 10 children each made a similar chain; if a whole class of 27 children each made such a chain; if a school of 295 children made such chains; and finally if 1 million children made such chains.

Groves (1993) compared results on these items for grade 3 children in 1991 (non-calculator children) and 1992 (calculator children). The 1992 children performed better on all 9 items, with significant differences ($p \leq 0.05$) being recorded for all four multiplication items and the most difficult of the division items (375 ml, take 24 ml/day, how many days?) where over a third of the children in 1992 obtained a correct answer (all using a calculator) compared to none in 1991. The 1992 children were able to use their calculators more effectively largely because they were able to correctly interpret their answer of 15·625.

This is not surprising when one considers the results from two earlier items on the interview. The first item asked children to read 5·42 and then select from 542, 2, 5, 54·2 and 6, the number closest to 5·42. For the other item, children were shown $278 \div 39$ and "the answer found by someone using a calculator" – i.e. 7·1282051. They were asked firstly to read the number and then to say "about how big" it is or give a "number close to it". There was a significant improvement in 1992 children's ability to read 5·42 and 7·1282051 , with over 20% of the 1992 children knowing the approximate size of these decimals, compared to only one correct response for the 1991 children.

Interview 2

The second interview, which focused on number sense, was designed to complement the two tests and the first interview described above. A draft version of the *Framework for considering number sense* produced by McIntosh, Reys and Reys (1992, p.4) was used to ensure that critical aspects of number sense were included in this interview if they had not already been covered elsewhere. Items focused on mental computation, knowledge of numbers (including ordering of numbers within and among number types, relationships between number types and place value) and estimation.

Groves (1994) reported that children with long-term experience of calculators performed better on the 12 mental computation items overall, the 24 number knowledge items taken overall, and the 3 estimation items taken individually. Overall, their performance was better on 34 of the 39 items, with the greatest differences in performance in mental computation generally occurring on the most difficult items. Their pattern of use of standard algorithms, "left-right" methods and invented methods for mental computation items did not vary greatly from that of the non-calculator children.

Conclusion

The *Calculators in Primary Mathematics* project was based on the premise that the calculator, as well as acting as a computational device, is a highly versatile teaching aid which has the potential to radically transform mathematics teaching by allowing children to experiment with numbers and construct their own meanings.

Classroom observations show that calculators have been used for exploration, as counting devices and as recording devices, as well as for "number crunching". Their use provides a rich mathematical environment for children to explore and promotes the development of number sense by removing previous restrictions on the types of numbers children use, by exposing children to written symbols which they can easily record and manipulate, and by facilitating sharing and discussion.

An analysis of the interviews with grade 3 and 4 children shows that children with long-term experience of calculators performed better than children without such experience on a range of computation and estimation tasks and some "real world" problems; exhibited better knowledge of number, particularly place value, decimals and negative numbers; made more appropriate choices of calculating device; and were better able to interpret their answers when using calculators, especially where knowledge of decimal notation or large numbers was required. Written testing, with and without caculators, confirmed that children's understanding of the number system had improved and that they were somewhat more able to identify an appropriate operation in a word problem. No detrimental effects of calculator use were identified.

These results confirm the anecdotal evidence from project classrooms and support the assertion that the presence of calculators can provide a learning environment which promotes number sense. An initial survey of teachers' attitudes and practices of calculator use in the primary grades established that teachers supported creative use of calculators, but rarely used them in such a way. We believe that the primary reason for this was the lack of good models of use for them to follow. The *Calculators in Primary Mathematics* project has established such good models and has shown how calculator use can become an enduring part of the mathematics curriculum to benefit children's learning.

References

Australian Education Council (1990). *A national statement on mathematics for Australian schools* . Melbourne: Curriculum Corporation (Australia).

Cockcroft, W.H.(1982). *Mathematics counts* . London: Her Majesty's Stationery Office.

Curriculum Development Centre (1986). *Report on the UNESCO pilot project on the application of calculators to mathematics teaching in Australia* . Canberra: CDC.

Curriculum Development Centre and The Australian Association of Mathematics Teachers (1987). *A national statement on the use of calculators for mathematics in australian schools*. Canberra: CDC.

Duffin, J. (1989). *Annual report of evaluation of CAN component of PrIME project.* National Curriculum Council Primary Initiatives in Mathematics Education Project.

Ferres G.W. (1981). *An investigation of teacher attitudes towards the use of calculators in Grades 4 to 8 classrooms.* Unpublished M.Ed. Thesis, Melbourne: Monash University.

Groves, S., Ferres, G., Bergfeld, S. & Salter, S. (1990). Calculators in the infant school: The Victoria College Calculator Project. In Clements, M.A. (Ken) (Ed).*Whither Mathematics?* (Proceedings of the 27th Annual Conference of the Mathematical Association of Victoria, pp. 244-250). Melbourne: Mathematical Association of Victoria.

Groves, S., Cheeseman, J., Clarke, C. & Hawkes, J. (1991). Using calculators with young children. In O'Reilly, J. & Wettenhall, S. (Eds). *Mathematics: IDEAS*. (Proceedings of the 28th Annual Conference of the Mathematical Association of Victoria, pp. 325-333). Melbourne: Mathematical Association of Victoria.

Groves, S. (1993). The effect of calculator use on third graders' solutions of real world division and multiplication problems. In I. Hirabayashi, N. Nohda, K. Shigematsu & Fou–Lai Lin (Eds.), *Proceedings of the Seventeenth International Conference for the Psychology of Mathematics*. (Vol. II, pp. 9–16). Tsukuba, Ibaraki, Japan: University of Tsukuba.

Groves, S. (1994, April). *Calculators: A learning environment to promote number sense*. Paper presented at the American Educational Association Research Association 1994 Annual Meeting, New Orleans.

Groves, S. (submitted). *The effect of calculator use on third and fourth graders' computation and choice of calculating device.*

Groves, S. & Cheeseman, J. (1993). *Young children using calculators*. [Videotape]. Burwood: Video Production Unit, Deakin University.

Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Researcher, 15* (5), 5-13.

McIntosh, A., Reys, B. & Reys, R. (1992). A proposed framework for examining basic number sense. *For the Learning of Mathematics, 12* (3), 2–8, 44.

National Council of Teachers of Mathematics (1980). *An agenda for action – Recommendations for school mathematics of the 1980s*. Reston, VA: NCTM.

Shuard, H., Walsh, A., Goodwin, J. & Worcester, V. (1991). *Calculators, children and mathematics*. London: Simon & Schuster.

Stacey, K. (1994, April). *Calculators in Primary Mathematics: An analysis of classroom activities*. Paper presented at the American Educational Association Research Association 1994 Annual Meeting, New Orleans.

Welsh, R. (1992). To what extent do grades 3 and 4 children make spontaneous use of calculators for computation? In B. Southwell, B. Perry & K. Owens (Eds.). *Space – The First and Final Frontier* (pp. 568–573.) Nepean, NSW: Mathematics Education Research Group of Australasia.

Williams, Y. (1992) *Calculators in the classroom: Activities for prep to grade three classes*. Melbourne University: Unpublished manuscript.

Willis, S. & Kissane, B. (1989). Computing technology in teacher education in mathematics. In Department of Employment, Education and Training, *Discipline Review of Teacher Education in Mathematics and Science, Volume 3, Appendixes*. (pp. 57 - 92). Canberra: Australian Government Publishing Service.

Professor Kaye Stacey
Department of Science and
Mathematics Education
Institute of Education
University of Melbourne
Parkville, Victoria 3052
AUSTRALIA

Associate Professor Susie Groves
School of Mathematics, Science and
Environmental Education
Faculty of Education
Deakin University - Burwood
221 Burwood Highway
Burwood, Victoria 3125
AUSTRALIA