ARITHMETIC WITH A CALCULATOR: WHAT DO CHILDREN NEED TO LEARN?

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ABSTRACT

The Calculators in Primary Mathematics[1] *project was a long-term investigation into the effects of the introduction of calculators on the learning and teaching of primary mathematics. A wide variety of qualitative and quantitative data was collected. This paper analyses differences on a test of arithmetic using calculators, between Grade 3 and 4 children who had been in the project for at least 3 years and a control group. All children handled whole number calculations equally well, the difficulty being determined only by how many transfers from paper to calculator and vice versa were required. Project children were better able to handle calculations involving decimals or negative numbers and to identify the appropriate operation to be used in a word problem. This very important observation is supported by data from another source.*

INTRODUCTION

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, with a quantitative as well as qualitative research methodology. It commenced with children who began school in 1989. All children at the six project schools since 1989 have been given their own calculators to use whenever they wish. In 1993, the oldest children were in Grade 4, having used calculators throughout their schooling. Teachers have been provided with some on-going professional support to assist them in using calculators to create a rich mathematical environment for children to explore. The researchers did not supply teachers with ready-made 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 published four times a year. During 1992, the peak year of classroom support, 45 Grade K to 3 teachers in six schools were being visited.

The format of the *Calculators in Primary Mathematics* project and the basic philosophy underlying it were broadly similar to those of the CAN project (Shuard, 1992), a qualitative study of

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the "effect of long-term complete acceptance of calculators in the primary school classroom, from the age of six." (p 34) This project 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 that project. In contrast, the *Calculators in Primary Mathematics* project collected both qualitative and quantitative data about changes, including a controlled study of changes in the long-term learning outcomes for children, part of which is the subject of this paper.

For many years now, the potential of calculators to significantly change mathematics curriculum and teaching has been recognised. There has been widespread agreement amongst mathematics educators that calculators should be integrated into the core mathematics curriculum. However, these calls have been based on very scanty research evidence, especially for the early years of schooling. 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 and there are no long term published studies.

RESEARCH QUESTIONS AND DESIGN

This paper reports only one small part of the results of the *Calculators in Primary Mathematics* project, related to long-term learning outcomes for children. Other results can be found in Groves (1992, 1993, 1994), Welsh (1992) and Stacey and Groves (1994). Learning outcomes were studied by comparing the performance of children in Grades 3 and 4 (average ages 8.5 and 9.5 yrs) on a wide variety of mathematical tasks with the performance of children of the same age who were at the same school in the year before the calculator program was introduced. In this way, the performance of children who had had frequent calculator use as part of their normal school curriculum for at least 3.5 years was compared with that of the previous cohort. This previous cohort may have used calculators on occasion at school (all schools had at least one class set of calculators available), but they did not use them frequently, children did not own their own calculators and were not encouraged to use them as a normal part of their mathematics. The design also ensured that variables such as the teachers, the culture of the school and socio-economic background were held very nearly constant.

This paper focuses on the ways in which children's ability to use a calculator changed. It was hypothesised that with long-term experience, children would be better at using a calculator for straightforward calculations and for working out short problems in a real setting. Furthermore it was hypothesised that long-term calculator use would enable children better to identify the operation in word problems, an aspect of mathematics that is known to be hard (Hart, 1981). The reason for this was that children using a calculator to solve a problem need to make a very explicit choice of operation - they have to press the right operation button(s). In contrast, children using mental methods (in written or oral form) have a variety of methods available. It is, for example, well known that they often subtract by counting on, a process more like addition. They may divide by carrying out a trial multiplication or even trial additions (Stacey, Groves, Bourke and Doig, 1993). In mental or written work, the variety of options for actually carrying out the steps is large and can sometimes be done without conscious awareness (MacGregor and Stacey, 1993). With a calculator, there is less choice and it must be explicitly made.

METHOD

Items

A test, taking about 10 minutes, was administered by the teachers. The first eleven items (see Table 3) were presented in writing as calculations to be completed. The final three items were set in a real context. Items 12 and 13 require interpreting the decimal point for dollars and cents in both input and output. Children had to use a pricelist to find the cost of various meals and change from $10.00. Item 14 could be done by repeated addition or by multiplication. Nine crates of soft drink were pictured, all but one holding 24 bottles. The final crate held only 20 bottles. Students were asked to find how many bottles there were in total and to tick which operation keys they had used. This was to detect whether students had become more sophisticated in choice of operation (e.g. by using multiplication rather than only addition).

Table 1.
Maximum number of years of experience in calculator project for classes and allocation to experimental and control groups.

	1991	1992	1993
Grade 3	0 (control)	2.75 (results omitted)	3.50 (experimental)
Grade 4	0 (control)	0 (control)	3.75 (experimental)

Sample

The test was administered to all Grade 3 and 4 classes in project schools in 1991, 1992 and 1993, thereby including all children in the cohort of children immediately before the calculator project as a control group. 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 of 1991 children with 1993 children, while the grade 4 results compare 1991 & 1992 children with the 1993 children. The data from individuals new to the school or who otherwise had irregular calculator experience were omitted from this study. The number of children tested in each category is given in Table 2. The experienced sample contains a markedly greater proportion of the younger students than does the inexperienced sample (45.9% compared to

37.0%). This means that the results will tend to understate the improvement due to calculator experience.

Table 2.

Numbers of students by grade level and years of experience

	No experience	3 yrs experience
Grade 3	221	159
Grade 4	376	188
Total	597	347

RESULTS

The percentage of students correct for each question are shown in Table 3. The results are not reported separately for grades 3 and 4 because they are follow a similar pattern, with Grade 3 a little below grade 4. The mean number of items correct (out of 16) was 11.12 for grade 3 and 12.08 for grade 4. Most of the items were done well by both groups. Despite its higher percentage of Grade 3 children, the experienced group performed better on the test, especially on the harder items. Table 3 gives the percentages correct for each part of each item and records the differences which were significant using chi-squared tests. The results summarised in Table 3 are discussed below.

Table 3.

Comparison of facility of experienced and inexperienced groups on test items.

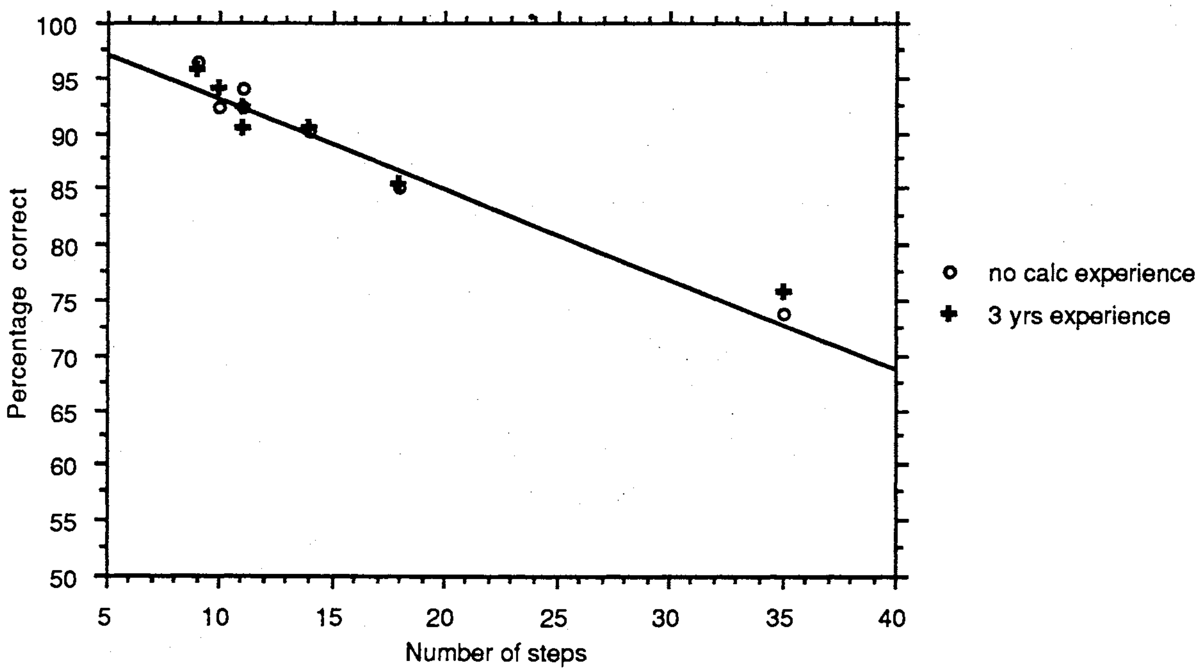
		Number of steps	Percentage of students correct		Level of sig'nce#
			0 years experience N = 593*	3+ years experience N = 346*	
Whole number questions					
Q1	186+492	11	93.9	92.2	n.s.
Q2	86x21	10	92.4	93.9	n.s.
Q3	712-368	11	92.2	90.5	n.s.
Q4	396+11	9	96.5	95.7	n.s.
Q5	1000000-192	18	85.2	85.3	n.s.
Q6	2458+2542	14	90.2	90.5	n.s.
Q11	1845+etc	35	73.7	75.7	n.s.
Negatives and decimals					
Q7	1833+65	12	51.3	67.3	p=0.0001
Q8	49-68	9	61.6	77.7	p=0.0001
Q9	21+84	10	74.9	82.9	p=0.004
Q10	187+4.92	15	75.9	82.7	p=0.015
Money problems					
Q12a,b,c	average facility		59.6	62.0	n.s.
Q13			47.6	50.6	n.s.
Identifying the operation					
Q14		30(by add'n)	53.5	60.4	p=0.03

\# n.s. not significant at 5% level * A small number of students did not hand in completed work.

Whole number calculations.

As can be seen from Table 3, these questions which involve only whole numbers (items 1,2,3,4,5, 6 and 11) were well done by both groups. There are no significant differences between the groups. The relative difficulty of these items can be explained by considering the number of steps required to calculate and record the answer. Item 4, for example, required 9 steps. Three key presses to input 396, one for the division, two to input 11, one key press for equals and then two for the writing of the two-digit answer of 36. The number of steps for each item is given in Table 3. Figure 2 shows how the facility of the whole number items depends very strongly on the number of steps involved. The regression line shown fits the data extremely well (percentage correct = 101.872 - 0.824*number of steps; $r^2 = 0.968$). For every extra step an item requires, an additional 0.8% of children made an error. We conclude that the errors in these questions are simple transcription errors and their incidence was not affected by the amount of practice the students have had at school.

Figure 2. Regression line showing facility of whole number items against number of steps required ((items 1,2,3,4,5, 6 and 11) for students with and without calculator experience.



Calculations with decimals and negatives.

Items 7,8,9 and 10 are also straightforward calculations but they do not lie near the regression line (see Table 3). It is here that we see strongly improved performance by the experienced group. There is no simple relationship with the number of steps, so these errors are not transcription errors. Instead they relate to knowledge of and familiarity with the decimal point and negative sign. The most common error in items 7 and 9 was to ignore the decimal point in the calculator display (giving 282 instead of 28.2 and 25 or 025 for 0.25). Where the question required typing the decimal point, as in Item 10 (187+4.92), many students again ignored it and gave the answer 679 (187+492). Similarly in item 8 (correct answer -19), common wrong answers were 19 or the ill-formed answer "19-". The frequency of these was much less in the experienced group. These observations collaborate other evidence (Stacey & Groves, 1994) that one of the main effects of the calculator project was that children became familiar with a much wider range of numbers than is normal in the primary school.

Money problems

Working with money with a calculator is an important real world task, but it is not easy because of the complex relation between the decimal point and the separator of dollars and cents. In item 12, the main difficulties were in entering amounts such as $1, $1.25 and 85c consistently, either as 1, 1.25 and 0.85 or as 100, 125 and 85 and interpreting the answers correctly (e.g reading $4.70 from 4.7 or 470). As is shown in Table 3, students with calculator experience were generally better than others on the money problems (items 12 and 13) although only the difference on Item 12c reached significance at the 5% level for the combined grade 3/4 sample.

Identifying an operation

Item 14 could be solved by addition of 9 numbers or by taking a shortcut with multiplication (e.g. 24x9 - 4 or 24x8+20). As one aspect of testing this hypothesis, it was predicted that a greater proportion of experienced students would realise that multiplication could be used here instead of repeated addition. A large majority of students indicated that they used addition (alone or with =). As only whole numbers are involved and there are 30 steps at most, the graph in Figure 2 indicates that the expected facility would then be 77% or more. However the facility is markedly less than this for both groups and transcription errors do not explain differences between the groups (see Table 3).

In order to examine whether the experienced group did identify the more sophisticated operation, the responses of students with the correct answer were analysed. It was judged that they had used multiplication if they indicated use of the multiplication button (and others: +or -or =), but not the division button. Of the 317 inexperienced students who had the correct answer, 22.4% had used multiplication. However, of the 209 experienced students who had the correct answer, 30.1% had used multiplication. A chi-squared test found this difference to be significant at the 5% level (chi-squared = 3.981, p=0.046). We therefore conclude that students with calculator experience were more likely to identify the more sophisticated operation correctly. We see this an a particularly important benefit of calculator use.

In addition to the test described above, the same groups of students were given a battery of pencil and paper tests, designed to probe many aspects of children's arithmetic. One section was on identifying the operations in word problems. A sample item was: *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? (circle the way you would do it.)*

a) 132+12 b) 132x12 c) 132-12 d) 132÷12 e) 12 - 1

As will be reported in a forthcoming paper, there was no overall change in the Grade 4 results but the experienced Grade 3 students were significantly better.

SUMMARY OF RESULTS

Very high percentages of children were able to use a calculator for simple arithmetic. The children who had only occasionally used calculators at school were as accurate as the experienced group. Accuracy in whole number items depended only on the number of steps involved in the item. However, the calculator experience had given children substantially more familiarity and awareness of decimal and negative numbers. This supports other observations made during the project (Stacey & Groves, 1994). There was some improvement in the ability of students to use a calculator to solve money problems, but these results were not strong. More calculator children used multiplication rather than repeated addition in a problem. Further data from the pencil-and-paper test supported the hypothesis that they were somewhat better at identifying an operation in a word problem. An improvement in this critical skill is important for progress in mathematics learning. The fact that the younger children (Grade 3) were over-represented in the sample adds strength to the results. Long-term calculator use by children from the first years of school can be recommended to enrich their experiences.

REFERENCES

Groves, S. (1992). Processes and strategies of third and fourth graders tackling a real world problem amenable to division. In *Proceedings of the Sixteenth International Conference for the Psychology of Mathematics*. (Vol. I, pp. 249-256). Durham: University of New Hampshire.

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 to be presented at the American Educational Association Research Association 1994 Annual Meeting, New Orleans.

Hart, K. M. (1981) *Children's Understanding of mathematics 11 - 16*. London: John Murray.

Hembree, A. & Dessart, D. (1986). Effects of hand-held calculators in pre-college mathematics education: A meta-analysis. Journal for Research in Mathematics Education, **17**, 83-99.

MacGregor, M. & Stacey, K. (1993) Seeing a pattern and writing a rule. 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. Japan, July, I-181 - I-188.

Shuard, H. (1992) CAN: Calculator Use in the Primary Grades in England and Wales. *NCTM Yearbook 1992*, p 33 - 45.

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

Stacey, K. & Groves, S. (1994, April). Calculators in Primary Mathematics. Paper to be presented at the Research Presession of the 72nd Annual Meeting of the National Council of Teachers of Mathematics, Indianapolis.

Stacey, K., Groves, S., Bourke, S., and Doig, B. (1993) *Profiles of Problem Solving*. Hawthorn, Vic: Australian Council of Educational Research.

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.