WHO IS BEING SENSmLE ABOUT CALCULATORS?

Derek Foxman, Consultant, and Janet Duffin, University of Hull

This paper has two parts each written by one of the authors. One of us (DF) presents a shortened version of a Review of International Research on the Availability and Use of Calculators in Schools 5-14 *(hereinafter called the Review), and the other (JD) presents her experiences of the Calculator Aware Number Curriculum (CAN) with primary children and with innumerate undergraduate students at the Hull University Numeracy Centre. The Review was one of two projects on calculators funded by SCAA and undertaken preparatory to the production of a discussion document to be published by SCAA in March,* 1997.

SOME ASPECTS OF A REVIEW OF INTERNATIONAL RESEARCH ON THE AVAILABILITY AND USE OF CALCULATORS IN SCHOOLS FOCUSING ON 5-14 YEAR OLDS

1. The availability and efficacy of calculators

The 1970s

According to Texas Instruments, the world's first electronic hand-held calculator was invented in 1967. The first production was announced in Tokyo by Canon Business Machines in April 1970. Although the output of the initial machines was printed on thermal paper, liquid crystal display was patented also in 1970 by a Swiss firm. Interestingly, neither of these pioneering countries make much use of electronic calculators in their schools even to-day.

In England a calculator project took place in schools in Durham in 1973-6 and the Inner London Educational Authority bought 200 calculators to develop their use in primary and secondary schools in the mid-70s. Most examination boards were permitting their use at least in some papers in mathematics examinations at 16+ by 1978.

In the USA too electronic calculators were being introduced into schools in the 1970s. For example, in 1976 there was a special issue of the leading American journal for mathematics in primary schools, the Arithmetic Teacher, which reported on some work with calculators in Chicago schools.

The Americans quickly began researching the influence of working with calculators on children's skills in computation. The results were, on the whole, not unfavourable, but there were doubts about some of the research designs and, therefore, the validity of the results. Suydam (1979) concluded that, provided 'the basics' had been learnt first, the use of calculators in the classroom did not harm calculation skills. It was 'pencil and paper' or algorithmic skills that were being referred to rather than mental computation an important distinction that is not always made when this issue is being discussed. Subsequently Roberts (1980) and, more definitively, Hembree and Dessart (1986) published research reviews which also concluded that experience with calculators in lessons did not harm calculating skills whether calculators or pencil and paper were used to test the skills.

The National Council of Teachers of Mathematics (NCTM) in America issued a statement recommending calculators should be used in schools. The USA's National Assessment of Educational Progress (NAEP), a programme of studies monitoring standards mainly in schools, had some calculator exercises in their 1977 surveys, with a small sample of children who were first trained to use them. An international conference held in Bulgaria in 1977 (Jacobsen, 1978) reported little activity in Europe with calculators in primary schools. In lower secondary schools in Sweden (ages 13 to 15) most classes were said to use calculators. Denmark was carrying out an experiment in ten secondary schools. Despite this activity, however, there was also resistance. Several articles in US professional mathematics education journals carried titles such as ' Mini-calculators: friend or foe?'

By the end of the 1970s calculators were in common use in the work-place in many countries and their existence in homes was already widespread. Many educators in several countries were expecting the electronic calculator to bring about a new era in the practice of calculation. Two seminal papers promoting this view in England were published at this time by Girling (1977) and by Plunkett (1979). The main factors in this new approach were to be an increased emphasis on mental calculation, and a decline, possibly an extinction of standard paper and pencil algorithms.

Plunkett maintained that the reasons for teaching standard written algorithms were out of date. The frequency of the actual use of non-standard as compared with standard methods could support this contention. Plunkett quoted research by Jones (1975) who found that over half the calculations he asked 11-year-olds to carry out were done by non-standard methods.

The 1980s

The Girling and Plunkett view of numeracy introduced the calculator, but gave precedence and emphasis to mental calculation. It implied what the Cockcroft Committee in their Report on mathematics education, published in 1982, called an 'at -homeness' with number. This was part of a broader definition of numeracy put forward in the Report, concerned not just with computation but with mathematics as a means of communication.

Cockcroft devoted a separate chapter to new technology - calculators and computers. The principal concerns were how they could be used to improve teaching and the extent they should change the content of or emphasis on what was taught. The Committee found that many teachers even at secondary level were resisting the use of calculators. They thought the research evidence (mostly from the USA) strong that calculators did not have an adverse effect on basic computational ability, including mental calculation (although it was noted that 'there was a failure to recognise the central place of working done in the head. ') Cockcroft recommended that low attainers should use them for all but the most straightforward of calculations. Calculators would replace logarithm tables. Boards were asked to allow all pupils to have calculators in their examinations by 1985, and all schools to have them available for their pupils by the same year. In other countries there is little reference to the use of calculators in tests and examinations. None of the international studies which have so far taken place have allowed the use of calculators.

Cockcroft drew attention to the fact that relatively little advantage was yet being taken of the possibilities that either calculators or computers offered as aids to mathematics teaching. Indeed, despite the expectations of a revolution in the making, a cross-national study of mathematics education at the beginning of the 80s showed that the influence of the calculator at that time in the 19 participating countries was negligible. The study was the Second International Mathematics Study (SIMS) ofthe International Association for the Evaluation of Educational Achievement (lEA). The extent of the lack of impact of the calculator revealed by this study may not have been fully recognised at the time because international reports on the project did not appear until the end of the decade.

By the mid-80s attention was increasingly on computers in schools in several countries such as the USA and Britain. In 1985 the Association of Teachers of Mathematics (A TM) in England launched a new journal, *Micromath,* which was largely devoted to the more sophisticated machine. The journal's first article on calculators was in fact on the new generation of graphical calculators. In the US the NCTM issued a document of recommendations for school mathematics, similar in tone to Cockcroft in Britain, *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989). But (Dick, 1988) says that calculator use is as controversial as it was in 1975.

In 1986 the late Hilary Shuard began directing a major curriculum development project in some primary schools in several LEAs, sponsored by the Schools Curriculum and Development Committee (SCDC). Known as PrIME, Primary Initiatives in Mathematics Education, it had the Calculator Aware Number Curriculum (CAN) as an important element. CAN children had calculators to explore from the age of 6 and were not taught the standard written algorithms. According to the project's evaluator (Duffin, undated) the development led to more open-ended teaching and learning in which many children encountered concepts such as decimals, and negative numbers, and were able to use more realistic numbers in problems much earlier than usual. Furthermore, mental facility and calculator use

developed alongside each other. CAN laste~years and there was a Continuation Project for twe-years ending in 1992.

The 1990s

A major project in Australia, similar to CAN, began in 1990. It continued until 1994, and produced very similar results to its English counterpart. Unlike CAN the Australian project had built into its programme the assessment of the progress of the young pupils. There were also non-calculator control groups in the project design which allowed a more objective appraisal of the influence of calculators. The CAN and the Australian equivalent were research projects conducted in a limited number of schools and classes. They succeeded in accommodating to the calculator because the teachers taking part developed their teaching and the mathematics curriculum to a more open-ended style.

Outside these projects, however, many people continued to be suspicious of the influence of the calculator, educationists as well as the consumers of education. In 1991 a comparative study of 20 countries at age 13 and 14 at age 9 was undertaken by a new organisation, the International Assessment of Educational Progress (IAEP) which had conducted a first smaller study in 1988. The findings of the second study showed that some of the most successful countries like Switzerland in Europe and Korea in Asia did not use calculators in the classroom until comparatively late in secondary education, while the USA and England, with low scores in number at both ages had comparatively liberal policies on calculator use (Lapointe et al., 1992; Foxman, 1992). There were also countries such as France and the former Soviet Union with good mathematics scores and policies which did not ban calculators in schools. These results indicated that there is little or no correlation between calculator use in a country and the overall performance of its students in mathematics.

In the USA, the NCTM promoted calculators strongly when its 1992 Yearbook was devoted to the subject. It was also suggested in this Yearbook that the standard written computation algorithms were no longer useful. In Britain during the same year *Micromath* published a series of articles on calculators which advanced their perceived virtues even more positively than Cockcroft had done 10 years before, and countered negative reactions suggesting that pupils may become too reliant on them. This time the writers had the backing of the CAN project, the National Curriculum (introduced in 1988), as well as further research, again mainly in the USA, but also from the national monitoring surveys of the Assessment of Performance Unit (APU) in Britain. These appeared to confirm that calculators do not harm children's computational skills, although the APU findings also indicated that those skills and children's understanding of number concepts, especially decimals, was limited (Foxman, Ruddock, and McCallum, 1991).

Costello (1992) in the same issue of *Micromath* referred to above, called his article, *'A Failed Revolution'*, stating that 'calculators have made remarkably little impact on school mathematics'. Overall, results from surveys, HMI observations and views of such as those of Costello suggested that calculators, while not to blame for low standards of numeracy in schools in Britain, were not contributing to their enhancement either. In other words Costello's meaning of 'failed revolution' IS 'failed to take place' rather than 'has taken place and failed to improve matters'.

Most recently teachers in higher education (Howson et aI., 1995) have expressed considerable concern about their perception of lower standards of mathematics undergraduates, and the calculator has been implicated as contributing to this situation (Gardiner, 1995). Surveys of primary schools indicate that there has been some increase in use of the instruments since the introduction of the National Curriculum (Askew et aI., 1993; Warren and Ling, 1995), but this is from a low base. Despite this, experiments with the more complex graphic calculators have started to take place in primary schools (paton and Christophides, 1995) and algebraic and geometric calculators are now available. However, the impact of the basic 4-function calculator on the mathematics curriculum still does not appear to be great - even in secondary classrooms where their generally easy availability has not yet resulted in a carefully worked out integration into the curriculum.

In 1995 the largest comparative study (of both mathematics and science), of nearly 50 countries, was undertaken - the lEA's Third International Mathematics and Science Study (TIMSS). England and Scotland participated in the surveys of 9- and 13-year-olds and the results for the older students were published late in 1996. The students came partly from grade 7 (year 8) and partly from grade 8 (year 9) classes, and data on the use of calculators in the classroom, as perceived separately by students and teachers, is given only for grade 8 (Beaton et aI, 1996). The students and teachers agree very well on the

amount of use. Unfortunately, however, it is impossible to draw conclusions about amount of use in relation to mathematics scores because some of the countries which use calculators a lot in grade 8 are known to introduce them for the first time in that grade (eg highly placed Pacific Rim countries such as Hong Kong and Singapore).

In 1995 also a project began in some primary schools in Barking and Dagenham with the aim of introducing 'continental' (mainly Swiss) methods of teaching number. The emphasis is on children's acquisition of fluent mental arithmetic and calculators are not allowed in the lessons devoted to the project (as they are in the national curriculum they are used in other lessons). In 1996 National Literacy and National Numeracy pilot projects began in a dozen or so LEAs in each subject area. Curricula have been produced by the project teams with guidance on the organisation of lessons that, in the case of numeracy, shows the influence of the Barking project. There is a stress on mental calculation, but, as calculators are in the National Curriculum, there is no ban on their use.

The calculator today, nearly a quarter of a century since its relevance to the mathematics curriculum was first put forward, has both detractors and protagonists in a variety of countries. Withdrawal of calculators from some papers in national tests and examinations here suggests that the official view is turning away from allowing pupils complete freedom of use of the instruments.

2. Issues

Few discussions of the efficacy of calculators in schools take into account both the potential of the calculator and the actuality of what has happened to the calculator in schools in the quarter century since the instrument was invented.

The potential of calculators: the need for support and guidance

- Calculators can only be used 'sensibly' in schools if teachers know what is sensible. According to Askew and Wiliam's *Recent Research in Mathematics Education* 5-16 'Open access to calculators does not lead to dependence on calculators, and can improve pupils' numeracy.' They refer only to the US short-term research and the CAN project which provide findings on the potential of the calculator.
  It is not sufficient to present research findings and expect others to be able to implement them without the support and guidance the project schools received.

- Research projects are supported and carried out in schools which agree to allow the experiment to take place.
  There is a need to consider how the features of the research could be introduced to other schools on a wide scale.

The actuality of calculator use

The availability of calculators and the teaching of number in different countries

- By the end of the 70s the price of calculators made them generally accessible. There was widespread availability in the home and workplace. Despite the upbeat recommendations of many educationists the lEA's SIMS (1980-2) demonstrated that, in the participating countries schools (including Britain) their impact had been negligible. Since then availability has varied considerably between countries with Japan and Korea banning them until quite late in secondary education, and England and Scotland being the most liberal of the participants in international studies in 1991 and 1995. Whatever the availability of calculators in primary schools the evidence suggests that they are little used.
  In countries that allow calculators in classrooms there is little evidence of carefully thought out integration into the curriculum.

- While countries differ in the extent calculators are available in classrooms there is universal agreement on the importance of the teaching of mental calculation from the beginning of schooling calculator related skills such as estimation and approximation is a later addition in some countries (Howson, 1991; 1995). Cockcroft in Britain and various documents for teachers in the US have

recommended the teaching of mental calculation with little effect until quite recently at least in England where it is in the NC.
Guidance in the teaching of mental calculation is needed.

Attitudes to using calculators

- Evidence from a number of surveys in England (Foxman et al1990; Warren and Ling, 1994); in Australia (Stacey and Groves, 1995); and Japan (Senuma, 1994) suggests that, despite a good deal of professed support for the use of calculators, teachers in primary schools (and lower secondaries in Japan) are reluctant to use them in the classroom. Japanese surveys has clearly revealed that it is 'university professors' who are mostly in favour. Surveys have also revealed prejudices on the part of significant numbers of both students and teachers that using calculators is 'cheating' or is likely to depress number facility.
  Guidance for teachers must demonstrate how mental facility can be developed alongside calculator use

Is there a link between the availability of calculators in schools and attainment?

- Our number scores were low in SIMS (1981) which took place before calculators were generally available in secondary as well as primary schools.
  The availability of calculators was not responsible for our initial low scores in number concepts and operations

- The availability of calculators in both primary and secondary schools increased considerably between 1982 when the Cockcroft report was published and 1987 when the last APU survey was conducted. Number scores fell while some other topic scores rose (eg probability and statistics). On the other hand higher scorers in number tend to have more experience with calculators, and this is a consistent finding in surveys. The relationship, however, is correlational, not causal and could be due to other, perhaps social factors - for example more affiuent children having more access to calculators and using them for a wider variety of problems. This is supported by an analysis of some 1987 APU data of ll-year-olds in attainment bands which were derived from the pupils' written test scores - the pupils were divided into five bands each with 20 percent of the sample according to their written test scores.

Percentage of pupils aged 11 with/without calculators at home, in attainment bands

Attainment Band	***Lowest 20 %***	***Top 20 %***
Calculator at home	69	91
No calculator at home	31	09

- As was reported earlier, comparative studies demonstrate that it is not only the top scoring countries that have high bans on calculator use or low scoring countries that have liberal calculator policies. However the TIMSS data on calculator use (Beaton et al1996) are not easy to interpret as the figures are given only for Grade 8 (Year 9) students. At this grade higWy successful countries like Singapore and Hong Kong appear to have high calculator use, but this is the grade at which those countries introduce calculators in the classroom. Furthermore, as we have seen, some countries like England in the primary years, allow free access to calculators but teachers are reluctant to use them. The evidence of the influence of existing calculator availability on performance is equivocal, but higher attainers generally have more experience of calculators. Nevertheless this cannot be interpreted as a causal relationship.

General conclusion:
There are two very different proven routes to student acquisition of number facility:
1. The development of mental calculation before calculators are allowed;

3. The CAN route developing mental facility alongside early development of calculator skills.

Neither has been used in Britain on a wide scale. They represent different pedagogical perspectives. What strategies can be used to introduce them on a wide scale? And what would be the comparative costs; would one be easier to introduce than the other?

References

ASKEW, M., and WILIAM, D. (1995) *Recent Research in Mathematics Education* 5-16. London: OFSTED.

COCKCROFT, W. H. (1982) *Mathematics Counts: Report of the Committee of Enquiry into the Teaching of Mathematics in Schools.* London: HMSO

COSTELLO, l(1992) A Failed Revolution. *Micromath* 8,1 (Spring 1992) 21

DEPARTMENT FOR EDUCATION (1995) *Mathematics in the National Curriculum.* London: HMSO

DICK, T. (1988) The Continuing Calculator Controversy. *Arithmetic Teacher* 35,8 (April) 37-41

DUFFIN, J (1992) *Calculators in the Classroom: The reports of the CAN component of the PrIME Project* (1987-89) *and of the CAN Continuation Project (1990-92).*

FEY, J (Ed.) *Calculators in Mathematics Education: NCTM Yearbook* 1992. Reston, Virginia: The National Council of Teachers of Mathematics

FOXMAN, D., RUDDOCK, G., McCALLUM, I., and SCHAGEN, I. (1991). *APU Mathematics Monitoring (phase* 2) 1984-1988. Slough: NFER

GARDINER, AD. (1995) Opinion. *Micromath* 11,3 (Autumn) 47-48

GIRLING, M. A (1977) Towards a Definition of Basic Numeracy. *Mathematics Teaching. 81,* (December) 4-5

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

HEMBREE,R, and DESSART, D.l (1986) Effects of Hand-Held Calculators in Precollege Mathematics Education: A Meta-Analysis. *J. for Research in Mathematics Education* 17,2 83-89

HOWSON, AG. and others (1995) *Tackling the Mathematics Problem.* London: The London Mathematical Society.

JACOBSEN, E. C. (1978) The Pocket Calculator - Some Implications for Schools. In D. C. Johnson and l D. Tinsley (Eds): *Informatics and Mathematics in Secondary Schools: Impacts and Relationships.* Amsterdam: North Holland Publishing Company.

LAPOINTE, AE., MEAD, N.A, and ASKEW, lM. (1992) *Learning Mathematics.* Princeton: Educational Testing Service

MICROMATH (Spring 1992) Calculator Feature 8,1 20-40

MICROMATH (Summer 1995) Calculator Feature 11,2 18-32

PLUNKETT, S. (1979) Decomposition and All That Rot. *Mathematics in School* 8,3 May 2-5

ROBERTS, D. M. (1980) The Impact of Electronic Calculators on Educational Performance. *Review of Educational Research* 50,1 71-98

SENUMA, H.(1994) In RE. Reys and N. Nohda (Eds.). *Computational Alternatives for the Twenty-first Century: Cross-cultural Perspectives from Japan and the United States.* Reston, Virginia:NCTM STACEY, K.,and GROVES, S (1994) *Calculators in Primary Mathematics.* Paper presented at the Research Presession of the 72nd Annual Meeting of the National Council of Teachers of Mathematics, Indianapolis.

WARREN, V., and LING, l (1995) Calculators Update. *Micromath* 11,2 22-4