1994

Issues in primary mathematics education: calculators: Research and curriculum implications

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Calculators: Research and curriculum implications

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Issues in primary mathematics education

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Published by
Mathematics, Science and Technology Education Centre
Edith Cowan University, Perth, Western Australia

Cover design by
Bill Adams

Desktop publishing by
Kathy McFaul

ISSN 1322-0195

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Preface

Calculators: Research and curriculum implications is one of a series of monographs on issues in primary mathematics education. It has been written to support initiatives in the development of student-centred learning programs at Edith Cowan University - programs designed to accommodate current views on effective adult learning strategies, as well as the development of professional and generic (key) competencies. Irrespective of the nature of individual learning programs, students and teachers working at undergraduate and postgraduate levels will find the series useful - either as a synthesis of currently available research findings and reference material, to identify potentially significant initiatives and developments in the area or as a classroom resource and guide.

The Contents and Introduction for this monograph have been designed for easy perusal, permitting rapid appraisal of its usefulness and relevance for a particular purpose. Although designed as a stand alone entity the monograph is part of a similarly titled self-contained module featuring videos/software/ print materials accommodating a wide range of teacher education programs. This independence has ensured a much wider appeal in a variety of teacher education applications.

While the content is not designed for direct utilisation as a classroom resource (these are listed separately), teachers would find the information, ideas, and examples presented, a valuable catalyst for both rationale and program construction.

Kevin Jones
Project Leader
Acknowledgements

We firstly offer special thanks to the Committee for the Advancement of University Teaching for their strong financial and pedagogical support to produce this monograph series, and other student centred learning materials.

We greatly appreciate the contributions of the following institutions/organisations and people:

Batchelor College, Northern Territory: Kathy McMahon and Ron Stanton for putting us on the right track, and reviewing our Aboriginal mathematics education material and funding applications.

Boulder Valley Films: Merle Thornton for her generous production of our video series on mathematics learning at Yirrkala Community School.

Edith Cowan University: Nerida Ellerton for her gracious advice and direction whenever it was sought. Alistair McIntosh for reviewing our Calculator and Written and Mental Computation monographs. Paul Newhouse for reviewing our Computer monograph.

Flinders University: Christine Nicholls for sharing her wisdom and experience so generously.

University of Melbourne: Helen Watson-Verran for her commitment to the production of the Yirrkala videos.

W.A. Ministry of Education: For their time, experience and expertise - Billy Kerr, School Welfare Officer, Kalgoorlie District Office, and the Principals and Staffs of Remote Community Schools within the Kalgoorlie District.

Yirrkala Community, Northern Territory: The Aboriginal people at Yirrkala for showing us the way.

Kevin Jones  Lorraine Kershaw  Len Sparrow

Special acknowledgement

Very special thanks to Lorraine Kershaw, our Project Office, who always had the drive to push for that extra mile. Her very substantial consulting expertise found a way through much rough terrain, and her research and writing skills were invaluable. Thanks Lorraine.

Kevin Jones
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Calculators range from basic four function types to those with sophisticated algebraic and graphing facilities. These options, their efficiency in reducing tedious and error-prone calculations with a pencil and paper, and their low cost have made them essential, commonplace tools at work and in the home. Their use in schools and their role in mathematics learning, however, have not been so readily determined or accepted. Debate continues about the numeracy skills children should have and ways in which they can best learn and apply these skills competently in their everyday lives. Curriculum developers have been recommending changes to the methods and tools used for school computational tasks for more than a decade, but like the suggested changes to mental and written computational practices in schools, the purposeful everyday calculator use by all primary children has been slow in being accepted.
The calculator controversy

Controversy still surrounds the integration of calculators in the teaching and learning of mathematics even though their use has been consistently advocated since the late 1970s (Plunkett, 1978; Agenda for Action, 1980; Cockcroft, 1982; W.A. Syllabus, 1989). Use in the mathematics classroom has not been widespread and often appears to have selective approval. For example, calculators often seem to be used for checking work but not computational tasks in problem solving activities, or available as a learning tool yet withdrawn for testing situations. Interested groups such as parents, teachers and employers continue to debate this issue, as uncertainties about the legitimacy of calculators in the mathematics curriculum are revealed in response to the changes being proposed by organisations and people in authority. The following examples illustrate some of the reactions provoked by these recommendations:

Parents:

"Why ... (are) schools still not teaching pupils how to use calculators?" (Fitzgerald, 1988, p. 8).

"But they won't know anything about the basics if they use calculators." (Comment at a recent school meeting).

Employers:

"a worrying decline in basic literacy and numeracy skills" (Miscalculation, 1989, p. 10).

"(employees who failed in school mathematics) now quite enjoyed working with numbers using a calculator" (Fitzgerald, 1988, p. 8).
Teachers:

"We must avoid the child's dependency on machines."
(Tyler, 1980, p. 19).

"(Calculators) allow children to display a knowledge of mathematics which surprises" (Groves & Cheeseman, 1992, p. 13).

Children:

"favoured the presence of calculators during most mathematics activities." (Hembree & Dessart, 1992, p. 29).

"some...still feel that using a calculator is tantamount to 'cheating'." (Hembree & Dessart, 1992, p. 30).

Curriculum developers:

"calculators...help children to understand numbers and to use numbers with enjoyment and knowledge."
(Shuard et al., 1991, p. 5).

"insisted that calculator use be assumed as integral parts of instruction and testing" (Payne, 1992, pp. 177-8).

These concerns and ideas are only some of many differing viewpoints about the use of calculators. They seem to stem from the ways in which people believe their expectations of children's numeracy skills are met by the practices of school mathematics. Most would agree that children should be provided with appropriate
opportunities to develop numeracy skills which are needed in their everyday lives and future employment. On the one hand a calculator is seen as aiding numeracy skills while those in opposition fear they will hinder mathematical proficiency. While this was not necessarily the intention of Girling (1977) when he proposed a definition of basic numeracy which focused on “the ability to use a four-function electronic calculator sensibly” (p. 4) nevertheless he was critical of school practices in mathematics. He believed that sensible use of the calculator should enable children to check results in many reasonable ways, understand number magnitude and its relationship to a particular task, and to make accurate, quick mental computations. He also questioned the role and use of written algorithms in helping children to understand number ideas.

At the time, Girling's view of basic numeracy was perceived as highly controversial. More recently others have recognised that having numeracy skills and being numerate are essential for adults in their everyday lives, and therefore to children's mathematical activity at school (Willis, 1990). Numeracy now is thought to cover broader contexts than Girling's original definition. Certainly many see the availability of calculators impacting upon the current curriculum and decreasing the need for many hitherto school taught arithmetical skills.

About this reading

Our aim is to provide the reader with a comprehensive picture of these and other significant issues and practices associated with calculators in primary school mathematics.

Firstly we will review attitudes, recommendations and research findings about the computational needs of
children in relation to mathematical understanding through mental and written computation, and calculator use. Secondly we will describe aspects of mathematical activity which could be enhanced through calculator use. Ideas on teaching/learning approaches and activities will be included with some reference to particular calculator projects in Australian and United Kingdom (U.K.) schools. This will be followed by a brief discussion on some proposed changes to the curriculum which could influence the expectations we might have of children's mathematical achievements. We will conclude with some suggestions for calculator implementation in the classroom.
The issue of whether primary school children should use calculators in their mathematics learning seems to have provoked considerable debate over a prolonged period (Wheatley, 1980; Hembree, 1986; Dick, 1988; Hembree & Dessart, 1992). Much of this controversy has revolved around the beliefs held about the importance of written computation skills in learning, understanding and applying useful mathematical knowledge. As explained in Dick (1988) and Plunkett (1978) many of those who are opposed to the use of calculators argue that knowledge and practice of the steps involved in written computational algorithms are necessary to understand mathematics and that basic skills will suffer. In response to this, proponents maintain that if children do not know what operation to choose in applying their mathematical knowledge to the solving of a problem and when to use it, the calculator by itself is not going to provide a correct solution (Wheatley & Shumway, 1992). These arguments however, need to be explored more fully to ascertain how and why calculators might aid mathematical learning. This section will review some perspectives on calculator
use through ideas expressed by parents, people in the workforce, teachers, researchers and those in authority.

What parents are saying

"Let's return to the basics ... teach them their tables ... they will know (then) the product of 11 x 12 when the batteries of the calculator fail" (Cortese, 1989, p. 10)

Views such as this in a letter to a newspaper, at school meetings and informal discussions with other parents and teachers epitomise many parent's concerns about calculators being used in everyday school mathematics lessons. Many have said that:

- young children will not be able to do simple addition, subtraction, multiplication and division tasks without a calculator;
- calculators will replace the ability and need to learn and remember basic facts; and
- these operations are best learned and understood through written computational procedures.

(Dick, 1988)

Some parents seem to feel that these written paper and pencil methods are best because that's what they used at school. Some parents also seem to support these methods because they are perceived as the best means of showing their child's progress in mathematics. They allege, therefore, that calculators would be detrimental to the learning of mathematics (Shuard, 1986; Dick, 1988).
Quite a different perspective on parental attitudes has been found, however, when parents are well informed of their children's involvement in mathematics programs incorporating calculator use. Some special calculator projects where children were not using traditional paper and pencil methods for learning about number ideas have been tried in a few schools (see the chapter on CAN projects for a full explanation of these).

Those of us who are involved in teaching primary mathematics are particularly aware that parent's attitudes and encouragement are important influences on children's mathematics learning (Shuard, 1991). The CAN projects took heed of these significant influences when they made special provisions to involve and inform parents. This included explaining to parents the types and purposes of calculator activities in which their children were engaged. As a result of this approach parent's anxieties diminished and as one parent said:

I wish maths had been like this when our older children were this age. I hadn't realised how little thought it takes to do a page of sums. This is much more challenging. (Shuard, 1991, p. 50)

Some responses to parents

Similar positive views to the one expressed above are held by many educators who have provided extensive reasons to support their beliefs (Shuard, 1986; Wiebe, 1987; Dick, 1988; Curriculum Programmes Branch, 1989; Fey & Hirsch, 1992). They have maintained that calculators should neither replace the learning of basic facts nor the need to use them in all forms of computation. Proficiency in their use, especially for estimation and mental computation, is recommended. The calculator is seen as
enhancing these skills and children's mathematical knowledge. It is also contended that the calculator cannot by itself choose the appropriate form of computation to use in a particular problem solving situation, check if the right keys have been pressed or if the displayed result is reasonable to expect. The child pressing the keys has to make all of these decisions to obtain a correct answer to the problem.

Consider a typical text book problem like the following:

In deciding upon a suitable method to produce a correct solution the child would firstly need to know that the problem required addition and multiplication computations to be carried out in a certain sequence. Some other considerations would be that subtraction and division were inappropriate and that multiplying the two numbers together first would give an area and not the perimeter.

Suppose a calculator was used for these operations and an answer of 147.56m was obtained. The answer does not make sense as the sum of two sides could be mentally estimated at more than 170m, therefore the distance around the paddock would have to be more than twice 170. To arrive mentally at this conclusion the child would need some number knowledge to round the 62.4 to 60 and the 113.8 to 110, to know some basic addition facts about 10 and 6, with possibly some multiplication or doubling skills. Thus knowing what operation to use, when to use it and deciding if the results made sense (by using estimation and mental computation) were all necessary mathematical skills for solving the problem even though a calculator was used.
Other arguments could be used to allay parents' doubts about the wisdom of learning mathematics with the aid of a calculator. These will be identified and described in later chapters of the reading as different aspects are reviewed.

**Attitudes and practices at home and work**

It would be unusual at home and in the workplace not to see hand-held calculators being used for most computational tasks other than very simple ones. Rarely would people use paper and pencil for the majority of everyday tasks particularly those associated with money e.g. checking expenditure, planning purchases (Wiebe, 1987). Money transactions outside the home are made quick and efficient by the facilities of modern cash registers. The proficiency of completing the computation task with a calculating device is only questionable if the operator keys in wrong numbers or chooses inappropriate operations or functions.

In other situations different kinds of calculators such as the scientific calculator enable people to perform computations which they could find too complex or unable to carry out if only pencil and paper were available. Fitzgerald (1988), who has undertaken extensive studies on mathematics used in the workplace, found that employees had very positive feelings about the use of the calculator in their job. Their reasons included:

- the ease with which some difficult written school methods could now be accomplished with a calculator e.g. subtraction by decomposition was a difficult task at school, but any form of subtraction could be carried out easily with the calculator;

- the potential for enabling all employees to be proficient with tasks requiring computation i.e. those people who were not "good" at school mathematics
did not feel disadvantaged in their job because they felt they could use a calculator with confidence;

✓ accessibility of different forms of mathematics to solve problems e.g. using programmed formulae or trigonometric and logarithmic ideas with the calculator to design patterns instead of feeling unable and overawed by the prospect of having to do the necessary calculations with paper and pencil;

✓ the simplicity of working with decimals rather than unwieldy fraction calculations e.g. using 3.142 or π instead of 22/7 thus reducing the need for extra steps and simplification of fractions if paper and pencil were used; and

✓ the elimination of errors in computation i.e. once the data is entered the device undertakes whatever type of calculation the operator chooses.

Employers on the other hand still maintained that potential employees should first be able to demonstrate mathematical competency in arithmetic tasks with pencil and paper and without the aid of a calculator, even though a calculator would mostly be used in their work (Fitzgerald, 1985).

To those who argue that people would be mathematically incapable if their calculator broke down, accept all calculator results even if they were ridiculous or use a calculator to perform very simple computations which could be done mentally, Fitzgerald (1988) has these replies.

1. Calculators are generally very reliable and so cheap that work environments should have spares available.

2. People should still learn estimation and mental computation strategies to judge if results make sense.

3. If a simple calculation is in the middle of a complex
computation then it would be easier to continue to use the calculator rather than reach for paper and pencil.

The second point made by Fitzgerald about estimation and mental computation has been discussed in detail, and in conjunction with ideas about number sense, in the *Mental and Written Computation* book of this series (Jones, Kershaw & Sparrow, 1994). However, a brief review of significant aspects will indicate that effective use of a calculator can also embrace number sense, mental computation and estimation skills.

When engaged in computational activities adults use number sense gained from their experience and understanding of number relationships to calculate mentally and make estimates (Sowder in Grouws, 1992). They use invented mental computation strategies rather than school taught written procedures to solve problems (Hope, 1986). In everyday situations as well as the workplace they make mental estimates rather than exact calculations for situations where an approximate answer is the most suitable e.g. shopping for groceries, estimating the time it will take to get to work by car to decide on the departure time from home. Calculators are only chosen as a computational aid when exact solutions are needed.

It has been argued that some skill in mental computation is essential to the checking of the reasonableness of results obtained by using a calculator. While this view has been supported by Fitzgerald (1985), he nevertheless found that employees often checked the reasonableness of results not through mental computation, but by familiarity of results expected from many previous similar tasks within a specific context. In addition although they could carry out the necessary computational steps on the calculator they had forgotten the written procedures and could demonstrate very little mathematical understanding of the
task. It appears that the learning of written procedures, which employees would have experienced at school, did little to promote their understanding and that they also employed calculator procedures on the basis of practised sequences. He felt that both employers and teachers have grounds to be concerned that calculator use would reduce people's efficiency in mental computation skills. He believed that mentally checking results would not necessarily occur and that these skills will be eroded if they were not regularly used.

**Teachers' attitudes**

Concerns from teachers like those expressed above are not uncommon nor are they dissimilar to parent's or employers' attitudes (Tyler, 1980; Dick, 1988; Fitzgerald, 1988; Shuard, 1991). Apart from the previously mentioned concerns about children not learning basic skills and that written computation is a good way to learn mathematics, teachers view calculator use as cheating or having limited use e.g. only useful for children to check their work, as a motivational aid or for occasional work on specific topics (Tyler, 1980). One teacher of young children remarked:

```
Oh, but they get too excited if you do something interesting like that - and I don't want them excited on a Monday morning, thank you. (Tyler, 1980, p. 19)
```

Perhaps this says more about the teacher's attitude towards teaching in general than it does about the use of calculators!
Not all comments by teachers are negative, as indicated by the following statements from some teachers of children aged 6 to 9 years:

I have found them (calculators) very beneficial with “slow children” ...

extremely useful in extending practical investigations ...

likely to encourage more mental arithmetic ...

creates a more confident and positive attitude towards mathematics ...

(Tyler, 1980, p. 19)

In spite of these encouraging signs, support from teachers for the use of calculators in teaching mathematics has been slow to develop. In the early 1980’s less than 15% of primary teachers in both Australia and the U.S.A. showed a willingness to use them (Ferres, 1981; Hembree & Dessart, 1992) - by 1989 some 55% of Year 5 teachers in the U.S.A. reported occasional use (Hembree & Dessart, 1992). Possible reasons for this are teachers' reluctance to change current practices and their lack of knowledge of the evidence showing the benefits of calculator use. In addition teachers may not know how to use a calculator nor what activities would be suitable for calculator use as text books tend not to incorporate relevant teaching ideas or tasks. Some teachers may also feel anxious about deviating from the security and comfort of the traditional way of teaching children to calculate.
Calculators: Research and curriculum implications
Research findings of the last ten years show very strong support in particular areas of the mathematics curriculum. Three broad groups of investigation have been identified.

1. Children's mathematical achievements e.g. computational skills.
2. As an aid to learning mathematics - particularly for some number topics, and for solving problems where an appropriate procedure is found and the calculator is used for the necessary computations.
3. Type of access to calculators and children's attitudes to their use.

Studies in these areas have been quite prolific. The following summary will draw upon three well-known meta-analyses of more than two hundred studies - Suydam (1982), and Hembree & Dessart (1986, 1992). In this review it is not our intention to either describe the different methods used by these researchers for their meta-analyses nor to evaluate them. Interested readers can pursue those details for themselves.
Achievement in mathematics

Much of the criticism which has been levelled at calculator use has claimed that children's numeracy skills will decline. No evidence in the research has been found to support these assertions. Suydam (1982), in her review of 75 studies comparing results from children of all grade levels allocated to calculator and non-calculator groups, found that mathematical achievement was at least as high or higher for the calculator users. Using the findings of 79 studies on computation, concepts and problem solving with and without calculators Hembree and Dessart (1986) reported similar results on achievement. They concluded that the computational skills of average ability children improved. That is, when this group of children received computational instruction with a calculator their paper and pencil computational skills increased. No detrimental effects were found for children of low or high ability. However, when results were analysed by Grade level calculators seemed to negatively affect the basic skills of children in Grade 4. This could be attributable to the fact that in American schools (where the studies were conducted) children in Grade 4 spend a large proportion of their time in learning written algorithmic procedures and that possibly these interfered with the different algorithmic steps which were required when a calculator was used. A final advantage found by Hembree & Dessart (1992) was that all students with calculators achieved higher scores in test situations on items involving computation and problem solving.
Learning mathematics with a calculator

Research on children's achievements in problem solving when a calculator was used reported that:

- When children knew how to solve a problem but had difficulty with the actual computation, a calculator was useful; conversely if it was not known what operation to use in solving a problem, the use of the calculator made no difference;
- Children showed less anxiety when trying to solve problems;
- Children did not necessarily use more or varied strategies; and
- It was not clear whether more problems were able to be solved. (Suydam, 1982)

Calculators can help children to learn about number ideas associated with counting, basic facts and the four operations e.g. the learning of basic facts with the aid of a calculator made either no difference to or improved children's results (Suydam, 1982). It has been pointed out earlier that estimation is a necessary skill for successful computation and doubts were raised by Fitzgerald (1988) about adults and children making use of estimation skills when assessing the reasonableness of a result obtained with a calculator. Suydam (1982) found that many children did not use estimation skills and were often quite prepared to believe the accuracy of all calculator results. It would be interesting to see if this situation has changed over the last ten years. We suspect it has not.
Children's access and attitudes

We have stated previously that in the 1980s few teachers used calculators in their lessons (see Teachers' attitudes), which meant that few children used a calculator at school. Yet at that time about 50% of primary aged children owned a calculator while more than 70% of children came from homes where at least one family member owned a calculator (Shuard et al, 1991).

Children's attitudes towards calculators were shown to be very positive by the Hembree and Dessart (1992) analysis. They found that most children in the early years of high school believed:

<table>
<thead>
<tr>
<th>Attitude item</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculators make mathematics fun.</td>
<td>79.1</td>
</tr>
<tr>
<td>Mathematics is easier if a calculator is used to solve problems.</td>
<td>86.3</td>
</tr>
<tr>
<td>It is important that everyone learn how to use a calculator.</td>
<td>85.6</td>
</tr>
</tbody>
</table>

(p. 29)

Other reports about children's attitudes have been noted as classroom observations and responses to informal questions rather than as a result of formal data collection and analysis techniques (Hawkes, 1992; MacDonald, 1990; Mills, 1991; Shuard et al 1991). They noted that children were enthusiastic about using calculators and keen to pursue their own investigations of number ideas and relationships. Young children's ideas about what they believed calculators could do, however, may be of some concern if what Mills (1991) discovered is more
widespread. When he was talking with some eight year olds he found they believed calculators always produced correct answers and had limited functions. He cautioned:

"calculator work must attend to children's beliefs regarding the infallibility of the calculator and... that they give different answers to the same question"

(p. 15).

Curriculum recommendations

Recommendations about the role calculators can play in the learning of mathematics first appeared in the late 1970s and early 80s (Plunkett, 1978; National Council of Teachers of Mathematics, 1980; Department of Education and Science (Cockcroft report, 1982). More recently in Australia, syllabus documents, policy statements and curriculum guidelines on calculators and mathematics in schools have been written (Curriculum Development Centre & The Australian Association of Mathematics Teachers, 1987; Curriculum Programmes Branch, 1989; Australian Education Council, 1990). All of these bodies had common grounds upon which they based their proposals. Conclusions drawn from research evidence figured prominently in their rationales as did the implications of common everyday practices relating to the calculator, mental computation and estimation. All strongly urged a move away from the current emphasis on written computation as a means of developing children's understanding of number and recommended an integration of calculator use within the curriculum.

Some of these ideas are evident in the following statements by policy makers and curriculum developers:
The Agenda for Action (U.S.A.)

“All students should have access to calculators... should be integrated into the core mathematics curriculum... (produce) curriculum materials... (which encourage the use of the calculator)... in diverse and imaginative ways...” (NCTM, 1980, p. 9)

Cockcroft report (U.K.)

“...it is clear that the arithmetical aspects of the primary curriculum cannot but be affected by the increasing availability of calculators” (DES, 1982, para 387)

National Statement on Calculator Use (Aust.)

“... teachers should... ensure that the calculator is used both as an instructional aid and a computational tool in the learning process” (CDC & AAMT, 1987, p. 1)

Learning Mathematics (W.A.)

“...the calculator is not a substitute for the development of number concepts... but an additional aid in that process” (Curriculum Programmes Branch, 1989, p. 31)

Mathematics: Non-statutory guidance (U.K.)

“For most practical purposes, pupils will use mental methods or a calculator to tackle problems involving calculations.” (NCC, 1989, E6)

National Statement on Mathematics (Aust.)

“All students should leave school knowing how to use a calculator effectively.” (ABC, 1990, p. 109)
Implications of the above recommendations are considerable, particularly as curriculum change is advocated because of the potential impact of calculator use on children's mathematical achievements. The next two chapters will summarise the ways in which calculators can be used in learning mathematics, identify some specific mathematical topics where the calculator could be used to promote understanding and briefly describe two innovative calculator projects which exemplify these ideas.
We will not attempt to synthesise the proposals which many writers have made about ways of utilising the calculator in primary mathematics. Instead we have selected ideas which show an interesting range of viewpoints. It will be apparent, however, that these perspectives do not have fundamental differences and in fact it would appear that the differences lie only in the terminology chosen to describe particular approaches.

The W.A. Learning Mathematics Handbook (Curriculum Programmes Branch, 1989) states that the calculator can be used as an instructional aid and as a computational aid.

As an **instructional aid**, for example, it suggests that "the calculator can assist in the development of mathematical content ideas ... (such as) place value, multiplication as repeated addition and the learning of basic facts" (p. 30).

**Computational aid** is explained as helping children perform many needed calculations quickly and accurately, particularly to encourage the use of many strategies in solving problems.
It is not important to differentiate clearly between these two uses as many mathematical activities will incorporate both. Calculators used in these ways were also seen as supporting other resources such as concrete objects and structured aids. Having children create their own written records of computational tasks carried out with the calculator, followed by discussion about procedures and results were also suggested as integral to mathematical activity with a calculator. We found that children also needed to know what function was associated with the symbols on the calculator keys for them to use the calculator sensibly and proficiently.

De Nardi (1992) has also used the terms computational and instructional, though she associates the word tool with computation. Her model for computation with the calculator incorporates three steps - estimate, calculate and evaluate - as illustrated below:

1. **ESTIMATE** the answer: 27 x 56 is about 30 x 60 = 1800
2. **CALCULATE** using a calculator: 27 x 56 = 1512
3. **EVALUATE** the answer:
   - Is 1512 a reasonable answer for 27 x 56?
   - Is 1512 close to my estimate for 27 x 56?
   - Can I account for the difference between 1512 and 1800?

(DeNardi, 1992, p. 5)

A similar approach was advocated by Dick (1988) in what he termed a first principle in using calculators in the classroom. He proposed a second principle which stated that “the advantages of the calculator in speed and accuracy are fairly obvious to all students, but the
calculator also has many limitations" (p. 40), which students should be aware of e.g. the number of digits which can be displayed, and if precision was required the errors which could arise when subsequent calculations were made using those displayed figures. This concern does not seem particularly relevant however, to the primary classroom.

Using the calculator to check computations was considered by Thompson (1981) when he discussed the types of errors made by users entering data. He listed some possible kinds of errors made in this way and suggested the use of rough checking and exact checking techniques. Rough checking would generally involve some form of mental computation and estimation, while exact checking could use number relationships, such as the commutative property of addition, to check an answer. For example in the latter case, suppose 346, 2198, 672 and 1077 were being totalled and the user had begun with keying in 364, the exact check could start from 1077, or any addend other than 364.

In contrast to this Johnson (1978) felt using a calculator to check answers was quite unnecessary. He advised providing children with answer sheets to check their work. Yet children's practices indicate that the calculator can be a valuable aid for checking. Shuard et al (1991) found that children in the classroom used the calculator to check the results of their mental computations. In addition to this, she observed that calculators were used for:

- carrying out computations which were too difficult to do mentally;
- investigating number ideas to understand mathematics; and
- experimenting with the calculator functions to explore number ideas.
While it may be useful to categorise uses of the calculator in these ways it is perhaps more important to identify specific mathematical topics in which it could be used to advantage. (Clarke & Kelly, 1989). In doing so the objectives of the mathematics program and thus the appropriateness of the related activities should be taken into consideration. There is a huge range of printed material from which to choose suitable activities, but teachers should take care to ascertain their usefulness for assisting children's mathematical development and make their choices accordingly. This of course does not preclude the teacher from selecting mathematical activities because they are fun for the children and so encourage them to develop positive attitudes towards mathematics. Or an activity could be specifically chosen because it enables children to explore the functions of a calculator. What could be questioned is the practice of scheduling calculator lessons as though calculators were a mathematical topic to be studied, or as a reward or fill-in activity.

We have made a selection only of some appropriate activities and topics to illustrate how the calculator can be used to aid learning. These are place value, number patterns and relationships, number facts, fractions and decimals, and estimation. Other topics will be mentioned later in this section. It will be obvious when assessing each activity that many involve mathematical ideas which incorporate more than one topic.

Place value

Vanish (Curriculum Branch, 1985) is a place value activity which requires one calculator for each child in a group of two or more. The first child enters a number e.g. 349 or 25 318 depending on the level of ability of the child. This child gives an instruction to the others who have to make
one of the digits vanish e.g. an instruction like 'make the 4 vanish' or 'make the ones digit go' would mean that each child would have to use the subtraction operation and place value knowledge to make a zero appear in the place of the ones digit. Children take it in turns to give instructions until the display shows only zero. Variations of this activity are available under different names e.g. Wipeout (Mathematics Education Research Group & Shell Centre for Mathematical Education, 1982; Curriculum Branch, 1985; DeNardi, 1992; Hopkins, 1992).

**Line Up** (Australian Association of Mathematics Teachers, 1988) can involve the whole class or a group. Children must have their own calculator into which they key a number they choose. The teacher designates the range e.g. 'between 1 and 500'. Children are then required to line up in correct numerical order and then call out their number from the beginning of the line. The teacher should engage the children in some discussion during and after the activity. This activity is about recognition of numbers using place and face value, and number relationships.

### Number patterns and relationships

Teachers can devise numerous activities where children can explore number patterns and relationships with a calculator, and also encourage children to make their own investigations about numbers (Shuard, 1991).

**Counting by 10s(B)** (DeNardi, 1992) aims to have children investigate simple number patterns, but the same idea can be varied to explore more complex patterns. Using structured aids such as MABs and recording results each time the display changes, enables children to discuss changes, provide reasons for those changes, make comparisons between numbers and draw some conclusions about number values. The following procedure is an example:
Money trails (Lovitt & Clarke, 1988) can include the whole class in an investigation where children make decisions about what strategies to use in solving a problem involving money and measurements. The problem is to find out how much money would be needed to raise funds for a charity if coins were laid side by side on a particular length of the school grounds. Different coins could be used thus diameter measurements could be compared, providing information on length (diameter) and coin value patterns. Relationships of lengths can be estimated, discussed, measured and recorded by the children as they proceed to find solutions. The calculator assists in the computations associated with the problem, allowing children to focus on their chosen strategies rather than be hindered by the possible complexities of the required calculations.

Number facts

Bull's Eye (Blakely, 1979) can be played with any number of players. Each player must have a calculator. A new target is set for each round e.g. a target of 74 is set for Round 1. The ammunition is specified as 4 numbers and can remain the same for every round e.g. 9, 6, 4, 7. Players use the ammunition numbers (which may only be used once in each player's algorithm) and the four operations of +, -, x and +. The aim is to devise an algorithm which will give a solution as close as possible to the target number e.g. $9 \times 7 + 6 + 4 = 73$. Players secretly record their own algorithm. When a given time limit has been reached players show their algorithm, a check is made and a score allocated. A direct hit scores 10, a solution within 2 of the
target scores 7 and within 5 a score of 3 is given. Thus the solution of 73 would give a score of 7. The next round then commences. Target and ammunition numbers can be easily changed by using 10 tiles numbered 0 to 9 and drawing these from a container at random at the beginning of each round. The winner is the first to reach 30 or a similar suitable score. Children involved in this activity could be using and practising their basic fact knowledge, estimating results and also developing confidence in using trial and error as an appropriate strategy.

Haylock (1982) describes a novel way of providing these kinds of experiences through the use of what he calls a dud calculator. One of the keys, for example the eight, is declared inoperable, and children are asked to represent numbers accurately without using that key e.g. $278 + 882 = ?$.

A list of different methods for the calculation was drawn up for display and children were challenged to find other ways of achieving a satisfactory solution.

This activity can be varied by asking the children to make up problems for others to solve having decided what parts of the calculator were not working properly (Doig, 1988). For example, the following problem was devised. When $6 + 9 =$ was pressed 24 was displayed, for $8 + 15 =$ the answer shown was 38 and $16 - 7 =$ gave 2. The problem with this particular calculator was that the last operation was repeated when the “=” sign was pressed!

Example (our trial with Year 6 children):

Teacher: Find the total of $237 + 482 + 781$ using your calculator. But there is a problem. Two of your calculator keys are broken - the 7 and the 8 - and therefore cannot be used.
Table 1: Selection of children’s explanations of methods used

<table>
<thead>
<tr>
<th>Children’s explanations</th>
<th>Mathematical ideas used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well I pressed 200 + 30 + 3 + 4 (that’s the 237), then 400 + 60 + 20 + 2 (482) and</td>
<td>Basic addition facts, place value, expanded notation</td>
</tr>
<tr>
<td>300 + 400 + 60 + 20 + 1.</td>
<td></td>
</tr>
<tr>
<td>236 + 452 + 661 + 1 + 30 + 120. I took off the one from 237 to make 236 and then I</td>
<td>Basic subtraction facts - take away and complementary addition</td>
</tr>
<tr>
<td>added it back on - the rest the same.</td>
<td></td>
</tr>
<tr>
<td>First I got the 3 numbers and I put the 37 onto the 482 and the sum was 200 + 519 + 781.</td>
<td>Basic addition and subtraction facts.</td>
</tr>
<tr>
<td>Then I took 82 off the 781 and put it on the 519 and the sum was 200 + 601 + 699, and</td>
<td>N.B. Some agile mental computation here! We suspect this</td>
</tr>
<tr>
<td>that gave me the sum and I did not have any 7’s or 8’s in it.</td>
<td>child did not need a calculator to perform this task!</td>
</tr>
</tbody>
</table>

Fractions and decimals

Discovering ideas about decimal fractions can be another very good use of the calculator (Bennett & Cheeseman, 1990). Two different approaches were used by teachers when eight and nine year old children discovered that “odd” numbers appeared if they tried division examples which gave fraction remainders e.g. 11 ÷ 4 (Mathematics Education Research Group & Shell Centre for Mathematical Education, 1982). One teacher invited children to look carefully at the way the number was represented (to note the decimal point), asked children what the answer should be and then began to use structured aids to explore the decimal fractions or “bits” as the teacher described them initially. The other teacher used number pictures to illustrate values by drawing each successive digit after the decimal point increasingly smaller. Verbatim descriptions of some other interesting
investigations of decimals and fractions by the same age group are provided by Shuard et al (1991, pp. 18-23). Teachers' questions, children's responses and examples of their written records are included and would be useful as a guide for other teachers considering this approach.

Example (our trial with Year 5 children):

Teacher: During her interactions with a group of children the teacher noted that many of them regarded decimal numbers in the same way as whole numbers e.g. when counting in twos a child would repeat the whole numbers 2, 4, 6, 8, 10, 12; and when counting in 0.2 say 0.2, 0.4, 0.6, 0.8, 0.10, 0.12...

The teacher asked the children to set up their calculator with a constant of adding 0.2. They had to say and then record the next number displayed in the 0.2 sequence as they pressed the = key. At the fourth press the words zero point ten (0.10) and the display 1.0 were obviously different. Similarly with the words zero point twelve and the display of 1.2. This then provided discussion about what was happening. Materials of grid paper and Multibase Arithmetic Blocks (MABs) were used for further discussion and comparison. Other examples, e.g. 0.5, were tried as the children experimented with this decimal concept.

Estimation

*Shopping for groceries* (Williams, 1987) requires each child to have a calculator and paper and pencil to record estimates and calculator totals. Players take it in turns to select about 10 grocery items advertised in the newspaper or a supermarket catalogue and record their value. An estimate is made of the total and recorded. The calculator is used to see how close the estimate was.
<table>
<thead>
<tr>
<th>Variation 1:</th>
<th>A sum of money is stated and each player estimates what articles could be bought for this total.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation 2:</td>
<td>Each child makes a list of friends or relatives for whom they intend to buy a Christmas present. A budget is specified and again using a catalogue, estimates are made. In both cases the calculator is used to check estimates. Each of these could be made competitive by having players score a point for the closest estimate.</td>
</tr>
</tbody>
</table>
Some of the activities described in the previous chapter and many other interesting ideas with the calculator were first suggested and trailed almost two decades ago in four primary schools in the United Kingdom (Bell, Burkhardt, McIntosh & Moore, 1978). This project provided the impetus and the background for two specific calculator projects which were concerned with responding to perceived mathematical needs of children (DES, Cockcroft Report, 1982).

Calculator-aware number (CAN): U.K.

The CAN project in the U.K. was part of a National Curriculum project called Primary Initiatives in Mathematics Education - PrIME (Shuard et al, 1991; Shuard, 1992). One of its major aims was:

To develop the primary mathematics curriculum to take full account of the impact of new technology, concentrating especially on the importance of calculators for the number curriculum. (p. 7)
It began in late 1986 in England and Wales and initially involved twenty classes of six year olds. The project gained momentum as other schools joined and interest grew. Teachers were given professional support and were asked not to teach the written vertical methods of addition, subtraction, multiplication or division. It was important therefore that teachers designed activities which could facilitate children's exploration and understanding of these ideas. They provided materials for the children to work with but always allowed them to choose when they wanted to use the calculator. Calculators were used for all kinds of number activities and the only written work undertaken in number was to record results and explain methods used to solve problems. Concepts of number such as place value, large numbers, negative numbers, and decimals and fractions were developed in this way, that is, with materials, discussion, recording and the aid of the calculator. Investigations about number through experimenting with the calculator were common. Real life computations, especially those with large numbers, which would have been difficult without the aid of the calculator, were tackled with confidence. Children continued to use calculators in this manner throughout their primary schooling.

Two examples of children's work are shown in Figure 1. The first illustrates how an eight year old (labelled a "slow learner") found ways of making 19. The second is a record of a nine year old who was given a workcard which required her to make numbers by adding consecutive number.
Figure 1: Children’s accounts of their investigations with calculators

40 - 21 = 19
10 + 9 = 19
20 - 1 = 19
50 - 31 = 19
20 - 1 = 19
30 - 11 = 19
13 + 6 = 19
15 + 4 = 19
17 + 2 = 19
19 + 0 = 19

1 = 0 + 1
2 = impossible
3 = 1 + 2
4 = impossible
5 = 2 + 3
6 = 1 + 2 + 3
7 = 2 + 3
8 = impossible
9 = 4 + 5
10 = 1 + 2 + 3 + 4
11 = 5 + 6
12 = 3 + 4 + 5
13 = 6 + 7
14 = 2 + 3 + 4 + 5
15 = 7 + 8
16 = impossible
17 = 8 + 9
18 = 5 + 6 + 7
19 + 0 + 9
20 = 2 + 3 + 4 + 5 + 6
21 = 10 + 11
22 = 4 + 5 + 6 + 7

I think the next impossible number will be 32.9 am going on to find out.
23 = 11 + 12
24 = 7 + 8 + 9
25 = 12 + 13
26 = 5 + 6 + 7 + 8
27 = 13 + 4
28 = 1 + 2 + 3 + 4 + 5 + 6 + 7
29 = 14 + 15
30 = 6 + 5 + 6 + 7 + 8
31 = 15 + 16
32 = impossible
33 = 16 + 17

The next impossible numbers all double up, the next impossible number will be 64.
In a 1989 qualitative evaluation of the project (Duffin, 1991; Shuard, 1991) it was found that:

☑ children were very enthusiastic about mathematics;
☑ understanding was evident of some topics which had been previously thought too hard for a particular age level e.g. negative numbers;
☑ children were prepared to persist with trying to solve problems; and
☑ although low achievers had not made great gains their attitudes to mathematics were very positive.

**CAN project: Australia**

Similar number ideas to those listed above were used in two Victorian projects which began in 1990 with children in Prep and Grade 1 (Groves et al, 1990). Again teachers were given professional support but devised their own activities.

In the early free exploration stages of calculator use teachers noted that children enjoyed finding out how to enter their telephone number and experimenting with the function keys especially the constant function. Many children however, had difficulty with just the fine motor skills of opening and closing the calculator case.

Later among other discoveries children came across negative numbers. The teacher used this opportunity to discuss sub-zero temperatures and the children named these underground numbers!
Teachers observed that after the first term, calculators were mainly used:

- as a recording device
- for counting, using the constant function
- to aid number recognition
- in games
- for finding and creating patterns (including entering patterns such as 232323)
- as a diagnostic tool (e.g. initiating discussion about 21 vs 12; or 603 vs 63)
- to provide a natural setting for discussion - children can show the teacher what they have done and explain it.

(Groves et al, 1990, p. 248)

One of the aspects of this project which Groves and Cheeseman (1992) investigated was teachers' changed expectations of what young children could achieve and understand in mathematics. This is demonstrated by the following comments of a Prep/Grade 1 teacher:

Once upon a time in grade 1 we didn't extend beyond 50 at the most... understanding was thought to be limited... they really do have an understanding now, and they can translate what they are finding out on their calculator into concrete materials. (p. 12)

Evaluations of the above projects, classroom observations and results of research conducted on calculator use in
primary classrooms have prompted mathematics educators to suggest that changes should be made to the curriculum. The next section will review these and other reasons to support some proposed changes.
Even before much of the current research was available on calculator use, curriculum change in the primary school was being advocated.

Wheatley (1980) recommended that children should no longer be expected to carry out complex computations with paper and pencil and that these requirements should be removed from the syllabus.

Computations like dividing by a two digit number, multiplying by two or more digits and adding fractions with different denominators could either more appropriately carried out with a calculator he said or left until children were in high school. He felt that these measures would give teachers a lot more time to spend on topics which had more significance for everyday mathematical tasks. He recommended teaching ideas about estimation, interpreting data and using percents where the calculator could be used as an instructional aid for concept development.

These proposals were also endorsed by others (Wiebe, 1987; Williams, 1987). They particularly emphasised the
replacement of time consuming paper and pencil computations with mental computation, number sense, decimal fractions and the use of calculators for computational tasks which could not easily be accomplished mentally. Prominence should be given to the teaching of decimals at an earlier stage, they said, as children encountered these representations very quickly when using a calculator. In addition the almost universal adoption of the metric system obviated the need for many calculations with fractions. As Williams (1987) stated mathematics teaching “must include development and implementation of a curriculum that assumes the presence of calculators” (p. 9, our emphasis).

Changes in expectations of children’s achievements in mathematics have also been given as a reason for considering changes to curriculum content (Groves & Cheeseman, 1992). Preliminary findings from the Groves and Cheeseman survey on teachers’ expectations of children’s achievements in Prep to Grade 2 level indicated that generally performance was higher than expected. This was explained by results obtained on items which were based on attainment targets of the U.K. Mathematics in the National Curriculum (DES, 1989). Children were tested on their knowledge of large numbers such as reading 14,560, negative numbers like demonstrating understanding of what is meant by -7 and on decimal notation e.g., knowing which was bigger 0.75 or 0.8. As a consequence of these early findings they suggested that the calculator may enable some children to show proficiency in mathematical content that is beyond the levels currently stated in curriculum documents. Revision of some content areas was recommended while more flexibility was urged in allowing children in the early grades to explore number concepts such as decimal fractions.
These suggestions were also supported by Shuard et al (1991) as a result of their work on the CAN project in the U.K. They felt the use of children's own algorithms was of particular significance when they were explained by them in their own unique way and written in a horizontal form. This was different to the traditional vertical methods generally taught in classrooms following the guidelines set out in many syllabus materials. Children working with calculators clearly understood their own invented strategies and why they worked. Again the potential for curriculum change should be heeded not only at state and national levels but also at the local level where the teaching and learning takes place - the school and classroom.

Assessment practices

One other area is worthy of a brief comment - assessment practices and the calculator. If changes are to be made to the curriculum as a result of the integration of calculator use then this new content must also be assessed to gauge children's achievement (Hopkins, 1992; Payne, 1992). In Michigan a test was devised to provide information on children's knowledge of calculator keys, proficiency in computation with a calculator and awareness of calculator limitations (Payne, 1992). Results were not available on achievement levels in the newer content areas, but early findings suggest that children's estimation skills were quite poor. The implications for this are that considerable emphasis should be placed on this area in the teaching program as we have shown previously in our discussion.

Furthermore if children use the calculator to learn mathematics, questions which could arise are:

• why shouldn't the calculator be available during testing situations?
• how might this affect the testing context?

A pilot study, the Florida project, was conducted with a small group of elementary children to investigate ways in which the use of calculators might influence testing situations (Hopkins, 1992). The following table has been devised by us to summarise some of their preliminary findings.

Table 2: Calculators in tests: questions and findings (Florida project)

<table>
<thead>
<tr>
<th>Questions</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>How might test items need to be altered?</td>
<td>Numbers in problems were made more compatible with realistic situations and this change was found to be appropriate.</td>
</tr>
<tr>
<td>Did the test take less time?</td>
<td>Results were inconclusive.</td>
</tr>
<tr>
<td>How might prior calculator knowledge affect test results?</td>
<td>The elementary children had not used calculators at school and made more errors than the high school children.</td>
</tr>
<tr>
<td>Were children's attitudes towards tests affected?</td>
<td>Attitudes seemed to be improved.</td>
</tr>
</tbody>
</table>

While the above studies have as yet not provided us with much information it is obvious that as more schools use calculators in their mathematics programs test designs will be influenced by curriculum changes. Teachers can at least begin to consider and evaluate their current testing practices.

For many primary school teachers however, the issue of testing practices may be of minor importance compared to
how they might implement the use of calculators. Having been convinced of their benefits in the teaching and learning of mathematics teachers may still be faced with many problems such as the kind of calculators to use, strategies to employ when introducing calculators into the classroom, whether the Principal will be supportive, and how they might improve their own knowledge. The next chapter will endeavour to address some of the issues associated with these potential difficulties.
Programs for teachers

Perhaps the single most important factor which can impede successful implementation of an innovation is the teacher (Bitter & Hatfield, 1992). As Super (1992) noted their “characteristics such as attitudes, beliefs, experiences, and abilities have a major impact on the outcome of planned change” (p. 209). Research in the CAN and other projects has shown that teachers' attitudes towards calculators seemed to be more positive and calculator use more frequent where planned implementation programs were adopted (Suydam, 1982; Groves & Cheeseman, 1992; Shuard, 1992). In these programs teachers had access to differing forms of support including visits from advisory teachers, organised workshops, in-service courses, cooperative working groups and regular meetings among interested teachers. Teachers largely developed their own activities for the children in their classes and shared these ideas with other teachers rather than using the consultant or advisory groups as providers of resources. This type of approach was readily endorsed by teachers as they did not feel
dictated to by policy makers and curriculum developers (Shuard, 1992).

Support by parents

Keeping parents informed was seen as another influence upon implementation strategies. Inviting parents to school meetings, holding workshops and encouraging them to participate in classroom calculator activities are some of the ways in which parental anxieties can be addressed and endorsement gained for calculator innovation (Shuard et al, 1991, Bitter & Hatfield, 1992).

Some interesting material on planning and implementing parent workshops was produced for the Basic Learning in Primary Schools Project (Department of Education Queensland, 1985). These included guidelines for presenters in the form of introductory activities, points for discussion and activities which enabled parents to explore a variety of mathematical concepts and content ideas.

Leadership commitment

Effective implementation also depends upon leadership within the school and from state authorities as experience has shown (Bitter & Hatfield, 1992). Their conclusion was that apart from Principals and other educational organisations being aware of teachers' professional needs that “a solid commitment of resources, funding, and time” (p. 204) was imperative in implementing curriculum change. Participation by principals in the teaching program is also effective in gaining support for teaching and curriculum change. As one CAN principal said after he began teaching a project class “the doubts and worries were replaced by conviction and enthusiasm, so that I was able to be a much more convincing advocate” (Shuard et al, 1991, p. 49).
Classroom strategies

Implementation in the classroom could be assisted by considering some of the following strategies:

- instructing children how to care for their calculator;
- using calculators only after children have experience with structured and unstructured materials;
- providing time for free exploration of the calculator functions;
- encouraging and accepting children's invented algorithms in relation to calculator use;
- utilising and designing activities with real world numbers and contexts;
- providing opportunities for children to work in pairs and small groups on calculator activities; and
- creating mathematical contexts where children can assess whether the calculator, estimation or mental computation is the most useful strategy to use.

(Bitter & Hatfield, 1992)

The classroom teacher also needs information on which to base a decision about the type of calculator children should use. Shuard et al (1991) outlined the following useful points for teachers to consider:

✓ durability and cost;
✓ automatic switch-off if not used for a certain period and battery life e.g. solar power calculators might be best;
✓ clarity of display and size of keys compatible with children's motor skills e.g. large keys may be required for very young children; and

✓ what calculator their children need e.g. four-function calculators are cheap and simple but should have a constant function and arithmetic logic i.e. perform the operations in the sequence the user dictates, or scientific calculators use algebraic logic, round answers, use scientific notation and have many more features than four-function calculators.

Teaching style

One final issue which may be of some concern to teachers if they integrate calculators into their program is whether they would need to change their teaching style. It has been suggested that teachers' roles change in calculator classrooms (Duffin, 1992; Shuard, 1992). Teachers in the U.K. CAN project tended to act more as facilitators rather than attempting to direct the children's learning. They listened and observed more, asked questions which did not always need "correct" answers and designed less structured activities for the children. It seemed that the calculator environment actually fostered this kind of role in mathematics teaching - a style which was familiar to teachers because they used it in other subject areas.
The criticisms levelled at the use of calculators in primary school mathematics have been stated and rebuffed. Comprehensive research studies have found no evidence of a decline in children's numeracy skills. On the contrary overwhelming evidence from large scale classroom projects has supported the use of calculators in children learning about many number ideas, which have been previously taught using written computation methods: methods which did not assist understanding and often served only to reinforce negative attitudes towards mathematics. Topics such as place value, number patterns and relationships, number facts, fractions and decimals, and estimation can be successfully explored, understood and enjoyed, with the calculator, and without the use of traditional written procedures.

Changes to curriculum are being advocated at state and national levels, as syllabus documents make recommendations about levels of achievement affected by the integration of calculators in mathematical activity. Children's continuing use of calculators is also beginning to pose questions about the suitability of current assessment practices and the most appropriate level for
the introduction of some mathematical ideas, such as negative numbers.

No wealth of evidence nor strength of policy will effect change in primary school mathematics unless teachers adopt practices which embrace the everyday purposeful use of calculators. Each teacher must make a choice. To ignore these pleas for change is to deny our children satisfying and worthwhile mathematical experiences. We must make calculators count now as significant contributors to the quality of our mathematics teaching.
References


Classroom support materials


Research and investigation ideas for teachers

☐ Undertake a small survey to obtain the views of parents, teachers, business people, on the use of calculators in primary schools.

☐ What do children think about calculators?

☐ Design a teaching unit for a mathematics content area that integrates relevant calculator use.

☐ Critique selected calculator activities.

☐ Ask children to do some calculations on a calculator but with certain keys inoperable. e.g. Calculate 278 + 882 but the 7 and 8 keys are broken.
About the authors

Len Sparrow currently lectures in primary mathematics education at Edith Cowan University. Previously he was Primary Mathematics Education group leader at Nottingham Trent University, U.K., where he worked for eight years. Len has considerable experience in primary school classroom teaching having taught for sixteen years with a variety of age groups of children in English and Australian schools. Currently he is working on projects to introduce calculators into classrooms and in the induction year for primary school teachers.

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Kevin Jones is a lecturer in mathematics education in the Faculty of Education at Edith Cowan University. Previously he was a primary classroom teacher, principal and an advisor in mathematics education for the Ministry of Education, Western Australia. His current research work is focused on effective learning strategies for adults, and how these affect the education of teachers at the undergraduate and graduate levels.