Good Use of Technology Changes the Nature of Classroom Mathematics

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Powerful use of technology has the potential to radically alter the nature of classroom mathematics. Fundamental issues related to the use of technology can transcend the boundaries of the type of technology used and the level of schooling. Examples from the *Calculators in Primary Mathematics* project will be linked here with parallel examples and discussion from the research literature in order to explore some of the effects of technology on the nature of mathematical activity, classroom practice and the curriculum.

Introduction

> Technology is not just about tools — good use of technology shifts the very focus of mathematical activity in the classroom. (Jones & Lipson, 1995)

Research into the use of technology in mathematics education — the theme of this year's MERGA conference — has been extensive (for surveys of such research see, for example, Dunham, 1992; Dunham & Dick, 1994; Fey, 1989; Hembree & Dessart, 1986, 1992; Ruthven, 1995).

It would be both impossible and foolish for me to attempt such a survey here — impossible because of the limitations of time and space and foolish because another of the keynote speakers, Jim Kaput, is the author of an encyclopedic survey (Kaput, 1992) and is infinitely more knowledgeable on this topic than I am.

It is my belief that many of the issues provoked by the use of technology transcend the boundaries of the type of technology used and the level of schooling at which it is used. It is therefore my intention today, on Teachers' Day at this conference, to attempt to link my own research — into the use of calculators with young children — with the research of others, in order to explore some of the effects of technology on the nature of mathematical activity, classroom practice and the curriculum.

I will not attempt to provide a comprehensive coverage of major work in the area, or even of the different major uses of technology. Rather, I will select examples from my own experience with the *Calculators in Primary Mathematics* project, which I believe are relevant to these issues, and attempt to draw together common threads from the research literature.

The *Calculators in Primary Mathematics* Project

The *Calculators in Primary Mathematics* project was a long-term investigation into the effects of the introduction of calculators on the learning and teaching of mathematics in the lower primary grades. The project, which commenced with prep and grade 1 classes in 1990, involved approximately 1000 children and eighty teachers in six Melbourne schools. Children were given their own calculator to use whenever they wished. The project moved up through the schools, with the children, to grade 4 in 1993. New children joined the project each year on entry to school.

The project investigated four main questions: How can calculators be used in lower primary grades? What effect will calculators have on children's learning of number concepts? What changes will there be in teachers' expectations and the curriculum? What effect will their presence have on teachers' beliefs and classroom practice?

Teachers were not provided with classroom activities or a program to follow. Instead they were regarded as part of the research team investigating the ways in which calculators could be used in their mathematics classes. Feedback and support were provided through regular classroom visits by members of the project team and through the sharing of activities and the discussion of issues at regular teacher meetings and through the project newsletter.

Data was collected through regular classroom observations, teacher interviews, written teacher evaluation sheets and questionnaires, as well as large scale written testing and interviewing of children at grade 3 and 4 levels.

The Nature of Mathematical Activity in a Technology Rich Environment

> [The questions] mathematics educators and researchers ... are posing [are]: What are the *new* things you can do with technologies that you could not do before or that weren't *practical* to do?" Once you begin to use the technology, what totally new things do you realize might be *possible* to do? (Pea, 1987, p. 95)

It is obvious that technology opens up a huge potential tool kit which can be used to carry out many of the mathematical tasks which we have, in the past, regarded as an integral part of the mathematics curriculum. However, while first attempts at technology use have often been directed towards using these tools to alleviate some of the drudgery associated with finding answers, mathematics educators believe that the arrival of calculators will have a much greater effect — they will "change, permanently, what it is to do mathematics and what mathematics we ought to do" (Kissane, 1993).

One of the aims of the *Calculators in Primary Mathematics* project was to document classroom use of calculators with young children in order to demonstrate to teachers what new things become practical and possible when children have access to calculators. Project teachers, who were often initially uncertain about how they could use calculators at all with such young children, found that they were being used in their classrooms in diverse and unexpected ways (see, for example, Groves & Cheeseman, 1993; Groves, Cheeseman, Dale & Dornau, 1994; Stacey, 1994a; Stacey & Groves, in press). More importantly, one of the overwhelming responses from project teachers was to report that the nature of children's mathematical activity changed — children were much more likely to be engaged in open-ended, exploratory activities, where they were in control of the level of mathematics at which they were working. One infant teacher described it this way:

> I'm a lot happier to go where the children want ... it's a lot less teacher directed... The calculators have enabled us to do that ... You don't have to structure things so that you know the answer will be within their reach... If the children want to find out stuff, I say "go for it"... because I'm not so worried about them finding out things they won't understand anymore... I think I'm being a lot more open-ended with their activities... I'm putting more on them to do more finding out. I'm just sort of starting them off ... The activities I try and do with them are the ones they can take themselves where they want to go ... You never know what's going to happen.

Numerous examples of very young children exploring highly sophisticated number concepts were recorded. For example, in many prep classes, the calculator was used extensively for counting, by using the built-in constant function for addition and, often, recording the numbers obtained on long vertical strips. One child, Alex, stated that he was going to count by 10's to 1050. How did he know, at age 5, that 1050 would be in the sequence? Another child looked at her long "number roll" and observed that counting by 9's usually leads to the units digit decreasing by one each time, while the tens digit increases by one. Many children made conscious predictions about the next number in their sequence — even when they could not read the numbers aloud. Simon, also in prep, decided to count by ones on his calculator without doing any recording. He started at 1 000 000 — he knew it was a million because his mum had told him that a million has six zeros. Another child challenged him to reach "one million one hundred". At first, he said that there was no such number, but as he got to 1 000 079 he began to think that perhaps there was. When he finally reached 1 000 102 he was thrilled to see that he had "gone right past it".

Corbitt (1985, p.16) warned against making *a priori* assumptions about the appropriateness of mathematical topics for primary children. With calculators, large numbers, decimals and negatives all became available through counting. Counting backwards lead some children to encounter negative numbers. In one prep class where children had been discussing and drawing "what lives underground?", Alistair said "minus means you are going underground". When questioned what would be the first number above the ground, he said "zero". Other grade 1 and 2 children began using their calculators to count by decimal numbers. For example, one girl counted aloud as she used the constant function, saying "point one, point two, ... point nine, point ten". She then noticed that the display on her calculator showed something different and worked out why this should be so.

Having the support of a calculator enabled counting to assume a much more prominent place in mathematics lessons. Although all of the teachers continued to use concrete materials as the basis for their mathematics teaching, counting no longer needed to be tied to the rather small range of numbers which can feasibly be displayed with such materials.

Some children, of course, were still struggling with number recognition and some were very uncertain about all aspects of the calculator. The wide range of skills and understandings present in any classroom appears to be highlighted by the presence of the calculator. Corbitt (1985, p. 17) comments that "student-directed learning suggests that students may become dispersed throughout the learning environment". One teacher commented that the calculator "provided a tool for me to understand a lot better the way they are thinking and processing than I have been able to do before". Another commented "I don't think I've ever been as concerned as to what the children know ... before. I think it has opened things up a little bit more and I'm more interested in them telling me what they know".

The fact that a technology rich environment supports more exploratory activity on the part of the learner has been confirmed at all levels of schooling for a wide range of technological applications. For example, Fey (1989) regards software such as *Cabri* (Laborde, 1990) and *Geometric Supposer* as aiming to

> restore the act of discovery and conjecturing to a geometry course that has become a deadly routine of proving things that have been well known for centuries, and to facilitate inductive reasoning by making multiple tests of conjectures easy to execute. (p. 246)

Fey cites Yerushalmy and Houde (1986, pp. 421–422) as stating that when using *Geometric Supposer* "students spent the majority of class time discussing and doing geometry rather than listening to a teacher talk about it."

Jones and Lipson (1995) vividly demonstrate how the use of technology can transform the modes of enquiry available for students. With access to the World Wide Web a reality in many schools, secondary data for classroom use can change from being merely numbers invented by textbook writers to fit chosen examples, to data obtained by other people for real purposes, which can then be used to answer quite different real questions posed by teachers and their students. The potential is now available to pose a question and then search the web to find data which might provide an answer. In their conference presentation, they illustrated this by asking the question "What is the 'lifetime', in test matches, of the captain of an Australian cricket team?" A quick tour of web sites allowed appropriate data to be captured into a word processor and transported into a graphic calculator for analysis — a stunning feat in itself! A box plot of the data showed its skewed nature, with a clear outlier — Alan Border.

Also in Victoria, the *Technology Enriched Algebra Project* (see, for example, Asp, Dowsey, & Stacey, 1993; Asp, Dowsey, Stacey & Tynan, 1995) addressed the issue of providing concept and process rich learning experiences in algebra through the use of appropriate computer software. Graphing software enables students to experiment with a variety of examples which promote intuitive understanding of the bahaviour of various functions. Preliminary results from this project suggest that not only will the emergence of technology lead to new directions in school mathematics, but that differences in tools will promote the development of different concepts.

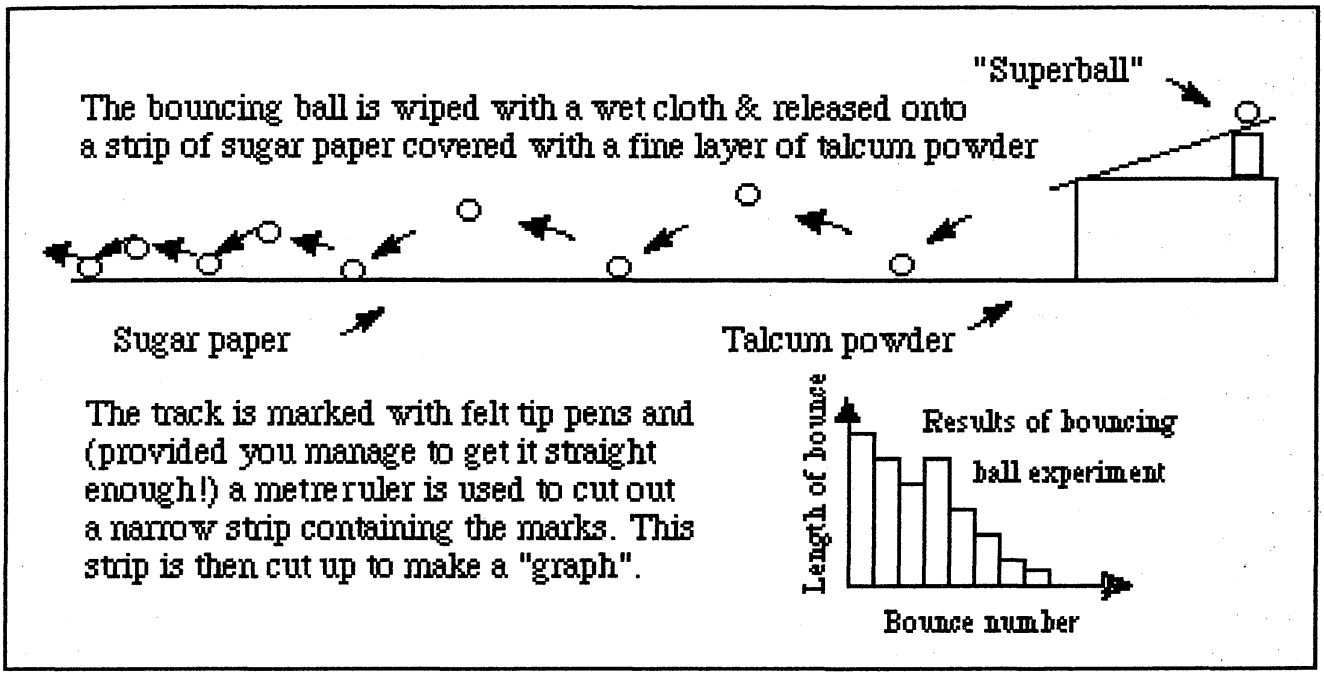

Figure 1. The bouncing ball experiment

The bouncing ball example, illustrated in Figure 1, originated from the *Mechanics in Action Project* (see Williams, 1989). The data produced can be plotted using a graphic calculator, in order to attempt to fit a curve (see Groves, 1989). This activity, which appears in a modified form in Asp, Dowsey, Stacey and Tynan (1995), leads to a very different type of mathematical activity than that experienced by students when plotting curves manually. I remember vividly my own attempts at fitting a curve to the data from this activity. While I feel I fully understand the functions involved in this and similar data fitting exercises, the actual *experience* of using relatively sophisticated technology, which nevertheless required you to fit the curves *bare handed* , provided me with a very clear view of the limits of my real intuitive understanding. I believe there is a great difference in the quality of these experiences and those where you are required to fit curves to *clean* data.

Flavel (1995, p.256), working in the upper secondary school, argues that while interactive computer software which provides multiple-linked dynamic representations "can enrich mathematical experiences in a way which is not possible with static pen and paper representations … for the software to have mathematical meaning to the learner, a supportive teaching learning model [is needed]". Such a model needs to "enable a community of learners to form where members can freely conjecture, justify and celebrate their learning".

The Nature of the Mathematics Classroom

> While technology provoke[s] innovation and in a sense makes it possible, the important changes are those that follow from changes in the teacher's beliefs about mathematics, teaching, learning, students, and the appropriate use of classroom time. Teachers need ... to make wise pedagogical decisions about how to proceed as students generate ideas and conjectures, many of which may be entirely new to the teacher. Lampert ... likens the experience to leading students on a field trip to a large city where each student is equipped with a motor scooter. (Kaput, 1992, pp. 548-9)

Widespread change in mathematics learning and teaching has not yet come about with the advent of calculators because it is no trivial matter to change these. Teachers need to rethink the nature and content of mathematics, the mathematics curriculum, mathematics teaching and mathematics learning, as well as develop new and substantially different skills for teaching and assessment (Willis & Kissane, 1989, p.74).

In the UK, the *Calculator-Aware Number* project (CAN), which commenced in 1986 under the direction of the late Hilary Shuard, was entered into as a curriculum development project. The CAN project, however, found that the calculator's full potential could not be realised without a change in teaching style, which, in turn, required substantial work on the part of teachers and constant support (Duffin, 1989, p.15).

In two of the six *Calculators in Primary Mathematics* project schools, one of the foci for research was the effect of the introduction of calculators on teachers' beliefs and practice. One of the original hypotheses of the project was that teachers would adopt a more open-ended teaching style as a result of the increased opportunities for exploration of number presented by the calculator.

Interviews with the seven teachers, over a three year period, were used to investigate their perceptions of changes in their mathematics teaching. Groves (1993a) found that most of these teachers claimed to have made substantial changes to their teaching of mathematics, with all seven commenting that their mathematics teaching had become more open-ended, while four teachers described their mathematics teaching as having become more like their teaching of language. At the same time, teachers saw calculators as encouraging them to talk more with the children, as well as providing opportunities for children to share and discuss what they have done — five of the teachers specifically mentioned more sharing and discussion as a change in the mathematics teaching. For example:

> I've had to really encourage them to share what they've done. I think I've always done that in language. I haven't really done that very much at all in maths before. What I see in the use of calculators and how it's changed my maths teaching is that I think I'm teaching maths now more in a way that I've been teaching language for a while, and I've always taught maths much more formally ... . It certainly encouraged me to talk to the children much more in maths, and discuss how did they do this, why did they do that, and getting them to justify what they're doing, which I guess previously I haven't done in maths. Much more discussion and sharing.

In a similar vein, Kennedy (1994) — in an article which likens the effect of graphic calculators on mathematics teaching to the effect of compact discs on the record industry — describes how deciding to allow students to use graphic calculators in his own calculus class changed his whole mode of teaching:

> The first thing I did was let them use their graphing calculators all the time. The next thing I did was to start every class with a problem, which the students would talk out until a solution emerged that they could explain to each other. What I discovered, of course, was how useless my crisp set of lecture notes had been all these years. The students were discovering the

> results *without me*, and then *showing each other how to solve the problems.* Every so often I still tie things together or generalise, but for the most part I let the course evolve through what the students are doing, and I provide the direction by the problems I select. I'm still not sure what the heck I'm doing, but I do know this: There is more mathematics going on in my classroom these days than there ever has been before. Now there are more people doing it. (p. 606)

Guskey (1986, pp. 7-10) presents a model of teacher change which assumes that the major motivation for teachers to change is the desire for improvement in student learning outcomes and that changes in teachers' classroom practice need to precede changes in their beliefs and attitudes. Clarke and Peter (1993) present a dynamic model of teacher professional growth, which traces its origins to Guskey's model. In terms of these models, technology can be seen as an external stimulus for change in classroom practice, which, through an iterative process of reflection and enaction, leads to long-term change in teachers' beliefs and practice.

The Nature of the Curriculum

> Impact of Technology on the Mathematics Curriculum
> Some mathematics becomes *more important* because technology *requires* it.
> Some mathematics becomes *less important* because technology *replaces* it.
> Some mathematics becomes *possible* because technology *allows* it.
> (National Council of Teachers of Mathematics, 1991, Transparency 34)

The 1990 report of the National Research Council, *Reshaping School Mathematics*, identified technology as one of several pressures to reshape mathematics education and argued for a "zero-based" approach to curriculum development — one which makes no *a priori* assumptions about the content of the curriculum, but instead "starts from scratch". In such a curriculum, the inclusion of any topic needs to be justified on its own merits with no area being immune from scrutiny (p.38).

The potential role of technology in redefining the school mathematics curriculum has long been recognised. For example, in 1976, the Swedish National Board of Education, set up the ARK project (Hedren, 1985; Brolin, 1990) to investigate three aspects of calculator use in grades 4 to 12. One of these was the possibility of altering the curriculum due to the calculator. While outcomes of the project were generally positive, Brolin (1990, p. 196) comments that many grade 4–6 teachers "see the teaching of algorithms as the primary function of mathematics courses. Consequently, they regard the use of calculators as a threat to their role as teachers".

In Britain, the *Calculator Aware Number Project* (CAN) project began to explore what a curriculum might look like if it takes seriously the implications of the availability of calculators. Participating schools had to agree not to teach formal written algorithms. Although there was no formal evaluation of the learning outcomes for students, the CAN project reported that children developed a wide range of strategies for carrying out calculations and reached a high level of numeracy for their age (Duffin, 1989; Shuard, Walsh, Goodwin & Worcester, 1991; Shuard, 1992).

The *Calculators in Primary Mathematics* project, like the CAN project, was concerned with a "bottom-up" approach to curriculum, as opposed to a "top-down" one which would dictate what was to be taught in classrooms. Teachers and schools were not required to abandon the teaching of standard written algorithms. Instead one research question was to establish the future role of pencil-and-paper calculations in classrooms where there was free access to calculators.

For many teachers one of the frightening aspects of calculator use is the possibility that children may encounter very large numbers, negative numbers and decimals "before they are ready". Teachers in the *Calculators in Primary Mathematics* project, who became comfortable with calculators in their classroom, took the opposite view. They saw their previous curriculum constraints as having imposed artificial boundaries on the children. For example, one prep and grade 1 teacher commented:

> Once ... in grade 1 we didn't extend beyond 50 at the most when we were counting. The understanding was thought to be limited for children of that age and, once they ran out of fingers and toes, that was as much as we expected them to do. But they really do have an understanding now, and they can translate what they are finding out on their calculator into concrete materials.

Many teachers — especially those teaching the youngest children — found that the presence of the calculator was forcing them to redefine their actual curriculum — whether or not this then conformed to the school's stated curriculum. As the project progressed, curriculum goals were being further challenged by the notion that the children were covering topics from higher grade levels.

The project hypothesised that as teachers became aware of the possibilities they would change their expectations of children's mathematical performance and, as a consequence, the curriculum would also change. In practice, while there appeared to be considerable change in the classrooms, it was impossible to discern any change in the stated curriculum. Perhaps it was an unrealistic expectation on our part that such complex issues could be resolved at the classroom or even school level, even in Victoria, which at least at the time of the commencement of the project claimed to have a "school-based curriculum". While it is likely that a longer time-frame may be necessary to produce discernible and lasting change is school curricula, it also needs to be acknowledged that the timing of the project was such that it was caught up in massive institutional changes which were happening throughout the Victorian school system — changes which would almost certainly have worked against curriculum change at that time.

The potential for curriculum change is by no means limited to the primary school. For example, Ruthven (1995, p. 232) likens the advent of the graphic calculator to that of its arithmetic predecessor, stating that "speculative writing has suggested that, in its emerging form, the graphic calculator subverts much of the traditional secondary mathematics curriculum".

Nevertheless, there is no question that curriculum change in general is lagging behind the potential created by the advent of technology. As well as the difficulties related to achieving curriculum change, there are some other factors which also need to be considered.

Firstly, while it is clear that technology increasingly has the capacity to *replace* much of the mathematics in the traditional curriculum, the question of which skills are necessary for achieving understanding remain (Fey, 1989, 241; Kaput, 1992, 533). Fey regards the question of an appropriate balance between skills, concepts and problem solving as "probably the most important issue for research in technology applied to our field" (p. 259).

A second, and related, issue is that of seeing how curriculum goals can be achieved in new ways — seeing what is made *possible* because technology *allows* it. Plunkett (1979, p. 5) argues that the advent of calculators provides the opportunity to abandon the standard algorithms, but notes that the "quite acceptable premise that children should learn how to calculate … [often leads to] the conclusion that they should be taught the standard algorithms." The *Calculators in Primary Mathematics* project team felt it important to document the types of activities engaged in by children because we believe that one reason why curriculum change has been so slow is the fact that many teachers with a commitment to children's development of number concepts resort to the teaching of standard written algorithms because they see no other way to systematically involve children in activities related to number.

A third issue relates to learning outcomes. Almost twenty years ago, Bell, Burkhardt, McIntosh and Moore (1978, p. 1) reported that "far from undermining basic arithmetic, the calculator seems to encourage and help children in developing their own number skills". Nevertheless, despite research evidence to the contrary (Hembree & Dessart, 1986, 1992), there is still a widespread fear that calculators will undermine mathematics learning (Wheatley & Shumway, 1992).

In order to investigate the long-term effect of calculator use on children's learning of number, the *Calculators in Primary Mathematics* project conducted an extensive program of testing and interviews, with and without calculators, at the grade 3 and 4 levels from 1991 to 1993. The last cohort of children at each year level who had not taken part in the project acted as the control group. Despite fears expressed by some parents, there was no evidence that children became reliant on calculators at the expense of their ability to use other forms of computation. The interviews showed that children with long-term experience of calculators performed better overall on both sets of computation items than children without such experience — in one set they could use any tool of their choice, while the other required mental computation only. These children also performed better on a wide range of items involving place value for large numbers, negative numbers and, more particularly, decimals. They also made more appropriate choices of calculating device and were better able to interpret their answers when using a calculator, particularly where decimal answers were involved. No detrimental effects were observed in either the interviews or the written tests (see Groves, 1993b; 1994; Stacey, 1994b).

Conclusion

> These examples ... show how ... calculators and computers can be used not simply ... to implement traditional practices within school mathematics; but that they can become central components within novel approaches to thinking and teaching, in which interaction with the computational tool is the key to its use as a thinking support and a teaching aid. It is important now that these more radical uses of computational tools should now be evaluated. (Ruthven, 1994, p. 32)

Research of the type reported here has established that technology can alter the nature of classroom mathematics. A substantial body of research also appears to show that the use of technology leads to positive learning outcomes. However, such research is fraught with difficulties. In particular, should assessment of learning outcomes include the use of the same technology which is used in the teaching? How can this be the case when one group has had exposure to the technology and the other has not? If the technology is not used in assessment, how can this fairly assess the group who have been using it throughout the teaching experiment? Dunham and Dick (1994, p. 441), speaking about the use of graphic calculators, describe this as the "Catch-22 situation in attempting to perform an experimental-control group study of achievement". They go on to state that "even if the researcher were able to match exactly the content and instruction ... one would immediately want to know *how* students used the graphing calculator and investigate *why* the differences appeared".

Thus research into evaluating the "radical uses" of technology now needs to move beyond the effectiveness studies and address the more fundamental questions about the actual processes of teaching, learning and thinking (Ruthven, 1995, p. 239).

Furthermore, for genuine curriculum reform to take place, it will be necessary to re-examine the curriculum in terms of the "big ideas" of its mathematical content and the pedagogy which can be employed to achieve understanding of these ideas. These notions will need to be separated from the existing web of skills and techniques which have been built up and set into concrete before the ready availability of technology as we know it at present.

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References

Asp, G., Dowsey, J. & Stacey, K. (1993). Linear and quadratic graphs with the aid of technology. In B. Atweh, C. Kanes, M. Carss & G. Booker (Eds.), *Contexts in Mathematics Education* (Proceedings of the Sixteenth Annual Conference of the Mathematics Education Research Group of Australasia, pp. 51–56.) Brisbane: Mathematics Education Research Group of Australasia.

Asp, G., Dowsey, J., Stacey, K. & Tynan, D. (1995). *Graphic algebra: Explorations with a function grapher.* Melbourne: Curriculum Development Corporation.

Bell, A., Burkhardt, H., McIntosh, A. & Moore, G. (1978). *A calculator experiment in primary school.* Nottingham: Shell Centre for Mathematical Education.

Brolin, H. (1990). The role of calculators and computers in the teaching of mathematics. In I. Wirszup & R. Streit (Eds.), *Developments in school mathematics education around the world,* (Vol. 2, pp. 189–208). Reston, VA: National Council of Teachers of Mathematics.

Clarke, David & Peter, A. (1993). Modelling teacher change. In Atweh, B., Kanes, C., Carss, M. & Booker, G. (Eds.). *Contexts in Mathematics Education* (Proceedings of the Sixteenth Annual Conference of the Mathematics Education Research Group of Australasia, pp. 167-175.) Brisbane: Mathematics. Education Research Group of Australasia.

Corbitt, M. K. (1985). The impact of computing technology on school mathematics: Report of an NCTM conference. *Arithmetic Teacher*, *32* (8), 14–18.

Duffin, J. (1989). *Annual Report of Evaluation of CAN Component of PrIME Project.* National Curriculum Council Primary Initiatives in Mathematics Education Project.

Dunham, P. H. (1992). Teaching with graphic calculators: A survey of research on graphing technology. In L. Lum (Ed.), *Proceedings of the Fourth International Conference on Technology in Collegiate Mathematics* (pp. 89–101). Reading, MA: Addison-Wesley.

Dunham, P. H. & Dick, T. P. (1994). Research on graphing calculators. *Mathematics Teacher, 87*(6), 440–445.

Fey, J. T. (1989). Technology and mathematics education: A survey of recent developments and important problems. *Educational Studies in Mathematics, 20,* 237–272.

Flavel, S. (1995). Using computational environments as tools for working mathematically. In B. Atweh & S. Flavel (Eds.), *Proceedings of the Eighteenth Annual Conference of the Mathematics Education Research Group of Australasia* (pp. 252–256). Darwin: Mathematics Education Research Group of Australasia.

Groves, S. (1989). Graphic calculators — An introduction. In B. Doig (Ed), *Everyone Counts.* (Proceedings of the 26th Annual Conference of the Mathematical Association of Victoria, pp. 395-400). Melbourne: Mathematical Association of Victoria.

Groves, S. (1993a). *Calculators as an Agent for Change: Teachers' Perceptions and Practice.* Paper presented at the Annual Conference of the Australian Association for Research in Education, Fremantle.

Groves, S. (1993b). 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 Education.* (Vol. II, pp.9-16). Tsukuba, Ibaraki, Japan: University of Tsukuba.

Groves, S. & Cheeseman, J. (1993). *Young Children Using Calculators.* [Videotape]. Burwood: Video Production Unit, Deakin University.

Groves, S. (1994). The effect of calculator use on third and fourth graders' computation and choice of calculating device. In J. P. da Ponte & J. F. Matos (Eds.). *Proceedings of the Eighteenth International Conference for the Psychology of Mathematics Education*. (Vol. III, pp. 33–40). Lisbon, Portugal: University of Lisbon.

Groves, S., Cheeseman, J., Dale, J. & Dornau, A. (Eds.) (1994). *Calculators in Primary Mathematics: The newsletters.* Geelong: Centre for Studies in Mathematics, Science and Environmental Education, Deakin University.

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

Hedren, R. (1985). The hand-held calculator at the intermediate level *Educational Studies in Mathematics, 16,* 163–179.

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.

Hembree, A. & Dessart, D. (1992). Research on calculators in mathematics education. In J.T. Fey & C.R. Hirsch (Eds.). *Calculators in mathematics education:1992 yearbook.* (pp. 23–32). Reston, VA: NCTM.

Jones, P. & Lipson, K. (1995, December). *Statistics towards the 21st centrury* . Unpublished paper presented at the 32nd Annual Conference of the Mathematical Association of Victoria, Melbourne.

Kaput, J. J. (1992). Technology and mathematics education. In D. A. Grouws (Ed.), *handbook of research on mathematics teaching and learning* (pp. 515–556). New York: Macmillan.

Kennedy, D. (1994). A tale of two CD's. *American Mathematical Monthly, 101* (7), 603–608.

Kissane, B. (1993). Sophisticated calculators: Mathematics for a new age. In T. Herrington (Ed.), *New horizons, new challenges* (pp. 227–240). Perth: Australian Association of Mathematics Teachers.

Laborde, J-M. (1990). *CABRI Geometry* [Software]. France: Université de Grenoble 1.

National Council of Teachers of Mathematics (1991). *Guide to Standards presentation materials.* Reston, VA: National Council of Teachers of Mathematics.

National Research Council (1990). *Reshaping School Mathematics: A Philosophy and Framework for Curriculum.* Washington, D.C.: National Academy Press.

Pea, R. D. (1987). Cognitive technologies for mathematics education. In A. Schoenfeld (Ed.),*Cognitive science and mathematics education* (pp. 89–122). Hillsdale, NJ: Lawrence Erlbaum.

Plunkett, S. (1979). Decomposition and all that rot. *Mathematics in School, 8* (3), 2–5.

Ruthven, K. (1994). Computational tools and school mathematics. *Micromath, 10* (3), 28–32.

Ruthven, K. (1995). Towards considered calculator use. In L. Burton & B. Jaworski (Eds.), *Technology in mathematics teaching — A bridge between teaching and learning* (pp. 231–256). Bromley, Kent: Chartwell-Bratt.

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

Shuard, H. (1992). CAN: Calculator use in the primary grades in England and Wales. In J. T. Fey & C. R. Hirsch (Eds.). *Calculators in mathematics education* (pp. 33—45.) Reston, VA: National Council of Teachers of Mathematics.

Stacey, K. (1994a. *Calculators in Primary Mathematics: An analysis of classroom activities.* Paper presented at the American Educational Association Research Association 1994 Annual Meeting, New Orleans. (ERIC Document Reproduction Service No. ED 373 968)

Stacey, K. (1994b). Arithmetic with a calculator: What do children need to learn? In G. Bell, B. Wright, N. Leeson & J. Geake (Eds.), *Challenges in Mathematics Education: Constraints on Construction* (Proceedings of the Seventeenth Annual Conference of the Mathematics Education Research Group of Australasia, pp. 563–570.) Lismore: Mathematics Education Research Group of Australasia.

Stacey, K. & Groves, S. (in press). Redefining early number concepts through calculator use. In J. Mulligan & M. Mitchelmore (Eds.), *Research in early number learning: An Australasian perspective.* Sydney: Mathematics Education Research Group of Australasia.

Wheatley, G. H. & Shumway, R. (1992). The Potential for Calculators to Transform Elementary School Mathematics. In J. T. Fey & C. R. Hirsch (Eds.), *Calculators in Mathematics Education* (pp. 1–8). Reston, Va: National Council of Teachers of Mathematics.

Williams, J. (1989). Modelling real data with FGP and Makefile. *Micromath, 5*(1), 51–52.

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

Yerushalmy, M. & Houde, R. A. (1986) The Geometric Supposer: Prompting thinking and learning. *Mathematics Teacher, 79,* 418–422.