New calculator technologies and examinations

Barry Kissane

Australian Institute of Education
Murdoch University

kissane@murdoch.edu.au
http://wwwstaff.murdoch.edu.au/~kissane

ABSTRACT: As graphics calculators are mainly devices for student learning, it is important that curricula and examinations are constructed to incorporate them in a coherent way. Three recent developments in graphics calculators are described and analysed to determine their implications for examinations. Symbolic manipulation on algebraic calculators challenges existing emphases in many examinations and their associated curricula. Flash memory allows calculators to be efficiently upgraded, but threatens the equity of students with different calculators or even the same calculator with different capabilities. Developments in memory storage increase the possibilities of students having access to significant text storage during examinations. Suggestions are made for ways of incorporating these developments into mathematics education in equitable and beneficial ways.

Calculator technologies change more quickly than educational organisations can usually cope with. Part of the reason for this may be the worldview of manufacturing companies, geared to annual releases of new products, rather in the way that automobile and electronics companies bring out a new model every year, attempting to provide a better product to consumers. Such activity seems a natural and unavoidable part of the competitive processes involved. Part of the reason for the differential rates of change is doubtless the inevitably slow rate of response to change of large systems of education. Regardless of the reasons, however, it is necessary for educational examination authorities to deal with this problem. This paper briefly describes and analyses three recent changes associated with graphics calculators.

To a significant extent, however unfortunate, the relationship between technology and examinations has a strong tendency to dictate the relationship between technology and mathematics generally throughout a course of study. Ideally, there is coherence between the conditions for learning and teaching mathematics and those for examinations. When students are permitted and even expected to use graphics calculators for learning, it is appropriate that examinations are conducted under the same conditions of calculator access. Elsewhere, my colleagues and I have amplified this argument in detail, described some of the consequences of using calculators in examinations and offered a framework for doing so. (Kissane, Bradley & Kemp, 1994; Kemp, Kissane & Bradley, 1995; Kissane, Kemp & Bradley, 1996). The present paper extends this work in the light of new developments.

Equity of access is an over-riding concern with the introduction of new technologies into examinations. As an example, when graphics calculators were first introduced into Western Australian examinations, care was taken to specify both minimally acceptable calculators and also calculator capabilities regarded as too powerful to preserve equity between students from different circumstances. The major concerns in 1995, when the relevant decisions were made, were with symbolic manipulation and with memory storage. Recent developments, outlined below, suggest that these are still major concerns.

Symbolic manipulation

The most challenging aspect of recent graphics calculators for mathematics education is unquestionably the development of affordable hand-held symbolic manipulation in the form of algebraic calculators (Kissane, 1999). In the past five years, three of the four graphics calculator companies have produced calculators capable of significant symbolic manipulation in hand-held devices. These devices have been manufactured with the mathematical needs of senior secondary school students in mind, and it seems likely that developments in this area will continue.

'Symbolic manipulation' has a range of meanings and of course there are a range of capabilities available on hand-held devices. However, the manipulations associated with elementary algebra (such as expansion, factorisation, solution of polynomial equations in the complex plane and evaluation of series) and with introductory calculus (such as differentiation and integration of elementary functions, evaluation of limits) are available on several machines. While many of these capabilities are available numerically on graphics calculators, a distinguishing feature of algebraic calculators is that *exact* solutions are provided. Thus, an algebraic calculator will evaluate indefinite integrals, give exact values for definite integrals and will give $x = \sqrt{5}$ as one solution of $x^2 = 5$. Kissane (1999) provides a few examples of these sorts of capabilities. Secondary school mathematics curricula do not usually progress beyond the manipulation capabilities of the algebraic calculators presently available.

Initial responses to such devices have generally involved banning them from use in examinations, because of understandable anxieties about their potential to confer undue advantage on some students. For example, in Western Australia, graphics calculators regarded as having 'extensive symbolic manipulation' capabilities were not approved for use in external examinations in 1998-2000, although other graphics calculators were deemed to be acceptable. (Curriculum Council of Western Australia, 2000a) Interestingly, Hewlett Packard's HP-38G calculator *was* approved for examination use in Western Australia, since its symbolic manipulation capabilities were regarded as unlikely to confer significant advantages on those students who used them, mainly because they were quite limited and also did not provide results in an easily recognised form. In Victoria, Australia, the same calculator was not approved for use in examinations, as it was regarded as having symbolic manipulation capabilities, and no official tolerance for such capabilities was provided for at all. (This latter decision has since been reversed, in fact.)

One early mechanism used to protect examinations from symbolic manipulation calculators was to disallow calculators with a QWERTY keyboard. The first example of this strategy was probably the College Board's Advanced Placement (AP) Program in Calculus (College Board, 2000a). The College Board's thinking appears to have been that a QWERTY keyboard was an easily-recognised and reliable indicator of computer-like capabilities, and there were too many threats to equity associated with allowing significant mathematical capabilities to some students and not to others. Perhaps ironically, one of the calculators explicitly mentioned as unacceptable by this criterion, Texas Instruments' TI-92, has since been replaced by a smaller device, but with superior mathematical capabilities, without the unacceptable QWERTY keyboard–Texas Instruments' TI-89. This (and other) algebraic calculators are approved for use in the present AP Calculus examination.

While initial unease about the use of algebraic calculators is understandable, as is the unease about the use of computer algebra systems in secondary schools, it seems dangerous for schools and universities to ignore such technological developments for too long in the name of equity in examinations. In this case, the main issue seems to be the place of symbolic manipulation in mathematics curricula, not only in the examinations.

It is worth remembering that computer algebra systems on calculators, like those on computers, can handle only symbolic manipulation, which is the least important part of the learning involved. For example, consider the factorisation of algebraic expressions. We want students to be able to decide *when* it would be helpful to factorise, *why* it would be helpful and *what* to do with the results. We also want students to know how factorising and expanding are related and what are the connections between factors and roots of, say, a polynomial. The actual process of determining the factors—the only aspect that a symbolic manipulation calculator will perform—is the least important, although it often consumes the most learning time; it also frequently consumes the most examination time. Similar kinds of arguments might be made for other aspects of symbolic manipulation, such as integration, solution of equations and so on. As Kennedy (1995) pointed out so eloquently, it is now possible for students to encounter more mathematical ideas with technology, without having to serve an extensive apprenticeship of symbolic manipulation first.

By their nature, many traditional examinations in elementary algebra and school calculus have rarely done a good job of distinguishing those with well-developed skills in symbolic manipulation from those with a high level of conceptual understanding. A short time spent attempting a current traditional examination with the aid of an algebraic calculator will provide adequate support for this claim. Consequently, it seems likely that many examinations, even today, would have trouble distinguishing a competent user of an algebraic calculator from someone with a deeper conceptual understanding of the ideas involved.

As for the case of arithmetic (Ralston 1999), it is at least conceivable that student's development of understanding of important ideas in algebra and calculus may be improved rather than eroded by significant access to computer algebra systems or algebraic calculators. However, those involved with and enthusiastic about significant and long-term use of computer algebra systems in secondary schools are mindful of the possible associated risks:

> If we were to comprehensively implement the White-Box/Black-Box Principle as mentioned above, there would exist the not insignificant danger that many students would be unable to do any mathematics without the help of a computer. … That cannot and must not be the goal of mathematics teaching; it would be completely irresponsible. (Kutzler, 1996 p. 34)

While such a cautious view is understandable, Ralston (1999) has made clear some of the risks associated with being too cautious and argued persuasively that a more adventurous response to technology is needed. Despite possible risks, experience suggests that the benefits to student learning outweigh the dangers, and that important gains can be made, provided due care is taken to do so responsibly. An early example was the seminal study by Heid (1988), who found that access to a computer algebra system was advantageous to students' conceptual learning without harming their skills development. Research, such as the study presently being conducted by a group at the University of Melbourne in Australia, has not yet answered definitively the question of whether long-term access to technology of this kind is as damaging as some people fear. (Stacey *et al*, 2000). Perhaps the arrival of algebraic calculators might stimulate us to reconsider the role of symbolic manipulation in school mathematics, if not mathematics more widely.

While it is possible to construct mathematics curricula that use technology differently during learning and examining, this does present problems too. It is interesting that the College Board has noted in its advice on calculator use in examinations that *Examination restrictions should not be interpreted as restrictions on classroom activities* (2000c, p.16). In practice, however, the economics of calculator ownership and use militate against students having one calculator during the learning and a different one for the examination—which would require each student to have two calculators. For most families in most countries, this is not feasible. So the question of symbolic manipulation on calculators in examinations and symbolic manipulation in mathematics curricula need to be considered simultaneously.

While preventing the use of calculators with symbolic manipulation in examinations would seem to resolve the issue, it is important to realise that such a solution is only a temporary one. With the passage of time, it seems inevitable that calculators with algebraic capabilities will become less expensive and thus more available to more students in more countries than is presently the case. A more considered response to the role of symbolic manipulation is needed, while there is still time left to undertake the necessary curriculum thinking and professional development of teachers and examiners involved.

Flash memory

The second recent development of graphics calculators of significance for examinations is 'flash memory'. This recent innovation in calculator design is described by Waits & Demana (2000, p. 61) as *(p)erhaps the single most significant advance in calculator technology that has huge ramifications for the future of calculators in mathematics classrooms.* An important characteristic of calculators is that they have memories in which information is retained, even after the calculator is switched off. Calculator operating systems are stored in ROM (Read Only Memory), which is relatively inexpensive at present. Information entered by the user, such as programs, numerical data, definitions of functions, and so on are all stored in RAM (Random Access Memory). RAM provides the working memory of the calculator and is relatively expensive. Flash memory has some characteristics in common with both ROM and RAM in calculators, but is different from each. It allows users to install software into the calculator for various purposes. The two main purposes are to upgrade the operating system of a calculator and to add capabilities in the form of new applications. A good description is available from Texas Instruments (2000a).

It is clearly of great value to have a mechanism to upgrade the operating systems of calculators in this way, as this obviates the problem of students having a calculator that is slightly out of date, as manufacturers make small adjustments to capabilities and operations. This is a much preferable to buying a new calculator—either for an individual student or for a school—as it extends the usable life of a calculator significantly. Indeed, it is comparable to the annual upgrade of computer operating systems, which do not require the purchase of a new computer—at least for a few years until operating systems make greater demands on speed and memory.

The use of flash memory for adding capabilities to a calculator is also potentially of great value to education, for similar reasons. Some capabilities can be added to existing calculators through the use of RAM, the working memory of the calculator available to users. The main way of doing so is through the use of calculator programs, written in the calculator's programming language, typically a fairly primitive algebraic language. The use of RAM and its consequences for examinations is discussed in the next section of this paper. But the significance of flash memory rests on the fact that it does *not* use RAM and thus can be more efficiently used. Flash applications can be written directly in machine languages, as Waits and Demana note:

> They can do more than user programs developed in the calculator's editor because they are written in more powerful software languages (C and assembly language) that tap into more of the underlying calculator system. Flash applications can also be faster than user programs for the same reason. (2000, p.62)

Flash memory applications can be easily added to calculators by schools or students with access to the relevant computer software and a personal computer, together with standard cabling; such equipment is commonplace in schools using graphics calculators these days. Most flash applications at present are available on the Internet for remote downloading. Like other educational products, some are available without charge, while others require (usually inexpensive) purchase. Examples from two of the major companies can be seen on their respective web sites. (Casio, 2000; Texas Instruments, 2000b). Examples are not restricted to mathematics, of course. Some flash memory capabilities allow the operating system of the calculator to communicate in a language other than English, so that calculators are readily used across international borders. Others offer scientific applications, such as a dynamic version of the periodic table of the elements, of value to students of chemistry.

From the perspective of education, flash memory capabilities offer exciting new prospects and indeed, move graphics calculators another step closer to computers in functionality. From the perspective of examinations, however, these same flash memory capabilities appear to present a new challenge. The essential challenge is that the availability of flash memory renders it very difficult to tell what capabilities a particular calculator provides to its user. Without flash memory, the functionality of the calculator is more-or-less known by its brand and model number. Although calculator RAM can be used for customising purposes, the kinds of capabilities offered by this are well known and controlled by the calculator programming language and text storage system. It is much less clear what is possible with a calculator with flash memory, and thus much more difficult for examination authorities to control the conditions of the examination. Even a competent calculator user would be hard-pressed to identify the capabilities of a flash-memory capable calculator without actually using the calculator. It is even more difficult for an examination supervisor to make such a judgement, especially as examination supervisors are not necessarily well-versed in the subjects they are supervising, but rather are employed to deal with the administration of the examination. So flash memory has the potential to significantly threaten equity of examinations.

The capabilities of a particular calculator depend on the amount of flash memory and the ingenuity of the programmer (who is not necessarily the user, of course). Hence, it is conceivable that flash memory might be used to provide capabilities not otherwise available to students and which are not acceptable to examination authorities. The most obvious of these involves symbolic manipulation. At present, it seems most unlikely that flash memory could be used to add a complete computer algebra system to a calculator that did not have one. It would presumably take a lot of memory and a lot of time to develop such software, so that someone interested in doing so may prefer to simply buy a more sophisticated (algebraic) calculator. However, when algebraic calculators are excluded from use in examinations, the incentives to add this sort of functionality become more attractive, and might even be seen by some as offering commercially attractive opportunities. It seems most unlikely that calculator manufacturers would do the necessary work of writing the flash memory applications, as they would presumably advise clients to purchase their more sophisticated calculators to meet their mathematical needs, but there is nothing to prevent enterprising third party software developers from doing so.

The technical question of precisely what is possible with various amounts of flash memory on various graphics calculators is not easy to answer, without greater technical skill than the author possesses. Presumably, however, the only real constraint is memory size, and all reasonable predictions would suggest that this is relatively easy to increase significantly, inexpensively and soon. The short term 'solution' of banning from examinations calculators with flash memory capabilities (or with flash memory of a certain arbitrary size) has some clear attractions for examination authorities. However, it is hardly likely to be a good long-term solution and will not be helpful for educational experimentation to further adapt the technology to good educational uses.

Memory size

The third challenge presented by calculator developments concerns the size of calculator memories. As noted earlier, graphics calculators have some RAM available so that they can be used for various purposes. Indeed, without *some* RAM, a calculator could not even perform arithmetical calculations. The most common three purposes for using calculator memory in this way are to store and graph functions, to store data for analysis and to store calculator programs.

Apart from allowing the calculator to be used for computational purposes, the availability of memory of this kind is useful as it allows a measure of customisation. As far as examinations are concerned, the most beneficial aspect of this is the possibility of storing short calculator programs in a calculator to enhance the capabilities. This is particularly useful to students with relatively less capable calculators (probably less expensive to purchase), as desirable features can be added easily. As an illustration, the College Board (2000b) identifies some minimum capabilities that should be met by students graphics calculators and advises students to use calculator programs to add any missing capabilities. Two common examples are to find the zeros of a function and to approximate numerically definite integrals.

To take advantage of this use of memory, students can write their own programs, obtain them from other people or acquire them from the Internet, usually without charge. For example, Kissane (2000) provides a number of short programs of these kinds (including programs for numerical integration and root finding) for a relatively inexpensive calculator that does not have such features inbuilt. A number of web sites provide access to programs of these kinds. Calculator programs of these kinds can be useful to students provided they have enough experience with their use prior to the examination to be familiar with their operation and interpretation. Without such experience, they are more likely to be a hindrance than a help.

Of course, it would not be possible for students to augment their calculator features in these ways if examination authorities did not permit memories to be used at will. Consequently, it would not be wise to demand that calculator memories be cleared for examination purposes, since this would potentially advantage students with more recent or more expensive calculators over others, a potentially significant source of inequity. Thus, public examination authorities such as the Curriculum Council of Western Australia (2000b) have tended to permit students to use calculator RAM without restriction in examinations.

While most of the concern about memory has focussed on what students can take into examinations with them, this has not been universally so, as the case of the US College Board. As well as signifying symbolic manipulation capabilities, a QWERTY keyboard also suggests a possibility for significant word processing capabilities, of concern to large testing organisations such as the College Board. The Board has also been concerned with the maintenance of test security for equating purposes between administrations, and students are explicitly warned about the use of calculators to jeopardise test validity by taking copies of test questions *out* of the examination room with them:

> Students must not use calculator memories to take examination material out of the room. They should be warned that their grades will be invalidated if they attempt to remove test materials from the room by any method. (College Board, 2000b)

Of particular interest is the use of calculator RAM to store text, rather than programs. Some calculators provide for this explicitly, while for others text can be entered as if it were a calculator program. Although such a 'program' does not run as a program, of course, it can still be accessed and edited and hence serves a similar purpose to text storage.

Historically speaking, mathematics examinations have usually been held with minimal external support for students, and generally strict rules on the carriage of notes and other kinds of prompts into examinations. Although table books have long been permitted, since there was no alternative to allowing students access to logarithmic, trigonometric or statistical tables, recent years in Australia have also seen students permitted to take examinations with some officially printed mathematical formulae available to them as well. For example, in Western Australia, prior to the use of graphics calculators in high stakes public examinations, students were permitted (indeed, expected) to have an official book of mathematical tables and mathematical formulae with them. They were also permitted to have drawing templates, commercial versions of which usually had various mathematical formulas imprinted on them. Such relaxations served as reminders that the valuable aspects of a mathematical education that were to be examined were not primarily involved with mathematical *memory*, but instead with the recognition, identification, analysis, use and interpretation of mathematical information.

When graphics calculators were permitted into examinations in Western Australia, the possibility of some students using RAM to store additional mathematical information to which other students might not have access was a source of concern, because of possible inequities between students with different calculators. Consequently, the Curriculum Council of Western Australia permitted all students to take some pages of notes with them into the examination, further reinforcing the view that mathematical performance is not primarily a feat of memory. (Curriculum Council of Western Australia, 2000b) While this does not remove inequities, it certainly reduces them, and little disquiet has been voiced about the practice since it began, at least in the case of mathematics. The number of pages of notes permitted (four, at present) is sufficiently small that it is assumed that the examination purposes are not undermined. (More concern has been expressed about calculator storage of information in areas other than mathematics, notably in chemistry, where it seems that the recall of factual information in examinations is viewed as more important.)

A long standing practice for students to revise for examinations is to make personal notes, forcing them to engage with the critical ideas, choose what is central, organise their thoughts, and so on. When students make their own notes to store in a calculator, the use of memory in this way can be educationally beneficial. On the other hand, notes for personal use or for insertion into a calculator that have been merely copied from other people are much less likely to be beneficial to student learning. Calculator notes can be electronically transferred between calculators, while handwritten notes can be photocopied; such practices reduce the educational potential considerably, and essentially just provide students with reference information.

Recent calculator developments, particularly the declining cost of memory, place some stress on this aspect of examinations, too. When a calculator has limited RAM, of the order of 20 kilobytes or so for storage purposes, the expediency of allowing students to take a few pages of notes with them resolves, or at least reduces, the inequity problems. However, as calculator memories become larger, as they seem bound to do, this solution may look less attractive to public examination authorities. For example, it is not clear how to deal with a calculator that permits thirty pages of mathematical notes to be stored. While a few pages of notes are likely to contain key formulae and results, thirty pages of notes threaten the intentions of the examination much more, allowing students to bring model answers, essay drafts, worked examples and other more extensive aids with them. Such an environment places a good deal more stress on examiners to construct papers that are equitable for students with and without such aids to memory. Of course, concerns of these kinds are exaggerated if students are permitted to bring more than one calculator into an examination with them.

Dealing with new generation graphics calculators

With examinations in mind, there are a number of possible responses to the issues raised by these three developments are briefly outlined in this section. In considering the possibilities, it seems important to achieve a balance between four overarching concerns: (i) maintenance of equity among students completing examinations with different technologies available to them; (ii) identifying and focussing on important aspects of mathematical education (iii) measured and thoughtful integration of new technologies into educational settings; and (iv) changing at a pace that teachers and professional development programs can reasonably accommodate. The project described by Stacey *et al* (2000) seems likely to provide especially useful information on these issues.

Eliminate examinations

Many of the problems identified above disappear if we dispense with mathematics examinations altogether. While such a drastic step has some attractions, there are many countries and contexts in which it is not a feasible option. Examinations are entrenched in the educational structure of many societies, and serve a variety of functions, especially those of competitive selection and credentialling. They seem especially durable in large systems, such as national and provincial systems, but may be more easily replaced with better alternatives in smaller settings such as a single class or school.

Use open book examinations

One way to eliminate the problems associated with increasing amounts of calculator text storage is to allow students to take examinations with fairly free access to their mathematics texts and associated notes, sometimes called 'open book' examinations. If the emphasis of a course is on students using their mathematics for the purpose of solving problems, such examinations may place students in realistic situations in which they are expected to efficiently make use of such resources, rather than focus on the (unnatural) situation of having access to very few resources. Once again, such a solution is difficult to implement on a large scale, but easier to handle on a smaller scale. A potential danger is that examinations can easily become too difficult when set under such circumstances.

Ban troublesome calculators
If examination authorities permit the use of only graphics calculators without symbolic manipulation, flash memory and large memory storage, it seems easier to deal with the problems raised by these newer technologies. This seems a rather short-sighted approach, however, and may merely serve to forestall the difficult decisions until later. Banning the use of calculators with the features described here will deny access to the considerable advantages they provide for both students and their teachers. Moreover, while such an approach can prevent the use of the new technologies at a local or national level, it is unlikely to impede the further development of technologies internationally.

Reconsider curricula
An examination is designed to measure performance in a particular course of study. One response to newer technologies is to re-consider the course of study itself, with the new opportunities in mind. For example, a mathematics course may be reconsidered under the assumption that students have regular access to computer algebra systems, either on an algebraic calculator or on a computer (or both). Such a course is likely to have less emphasis on routine manipulation as an end in itself, and more emphasis on the underlying mathematical ideas, on modelling practical problems, on interpretation of results and even on proof. For such courses, examinations with symbolic manipulation available to students would seem coherent with the main emphasis of the course, and flash memory would seem less troublesome. As Ralston (1999) has noted, curriculum development to deal responsibly and sensibly with the arithmetic calculator has not yet taken place, although the time has long past when it should, so that there is now some urgency required. It would indeed be unfortunate if the same international reluctance to deal with the curriculum problems was manifest for algebraic calculators as well.

Develop parallel courses
The previous response may be very difficult in transition, especially when circumstances meant that neither teachers nor students could be expected to have comfortable access to technology quickly. One possible resolution of this issue may be to construct more-or-less parallel mathematics courses, one of which allows unrestrained access to algebraic calculators and the other of which offers no access to them at all. This may permit ongoing experimentation for those who wanted it and allow others to phase in the necessary changes over time. While such an approach may present some structural difficulties in some countries, in others it may be preferable to continuing inactivity.

Use technology free components
Another possibility is to arrange for parts of examinations in which calculators are not permitted at all and other parts in which they are necessary for satisfactory performance. Again this seems especially relevant to the problem of symbolic manipulation. In fact, it is an approach adopted by the College Board recently:

> Beginning in May 2000, the free-response section of each examination will have two parts: one part requiring graphing calculators and a second part not allowing graphing calculators. This change in format is an effort to respond to heightened concerns with equity as more students may use graphing calculators with computer algebra system (CAS) features. (College Board, 2000c, p. 15).

Such a strategy is not without its dangers, one of which is that students may continue to be expected to develop by hand manipulation skills to the same levels as previously, which rather defeats the purpose of having access to sophisticated technologies. However, it may be a useful interim measure. Careful thought is needed to decide what continues to be appropriate for by-hand symbolic manipulation. The work of Herget *et al* (2000) and Goldenberg (2000) provide useful starting points for such activity, but more work is needed before a consensus will be reached.

An over-riding problem in responding to these new developments is that technological changes happen quickly and continuously, while educational responses to them happen slowly and discretely. Whatever measures are adopted to accommodate changes in technology need to keep the professional developmental needs of teachers in mind. For the same reasons, the difficult tasks of curriculum development and examination construction can only change at rates consistent with the professional people involved with them. It is unrealistic to expect too much change, and unlikely to be productive. On the other hand, to permit too little change to occur is just as problematic, since it increases the necessity for very substantial, and thus much more difficult, change at a later stage.

Concluding remarks

Graphics calculators are manufactured by international companies with global competitive interests, so that we should expect that there will be continuing changes in their capabilities and features. Decisions about calculators are made by commercial companies, often with some educational advice, and do not necessarily suit examination authorities in any particular country. Although many decisions are made to suit the large market in the USA at present, we should expect that there will be a rich assortment of calculators produced globally for various societies over the next decade.

Although we would prefer to have control over what technologies are available to our students in any particular country or even province, the realities of the new century are that some students will have access to technologies, including graphics calculator technologies, that cross international borders. Even when particular new technologies are banned from use in a particular setting, we need to be aware that it is increasingly likely that students and others will be aware of them and may even have access to them. In time, as costs decrease, it becomes steadily harder to prevent technologies from invading our schools and, in the present context, our examinations.

It is difficult to deal well with this mixture of circumstances at the pace with which educational decisions are generally made, shaped by the need for stakeholders to be adequately consulted and for the people involved to be able to cope with the change. As Leinwand (1994) noted, however:

> It is unreasonable to ask a professional to change much more than 10 percent a year, but it is unprofessional to change by much less than 10 percent a year. (p. 393)

While it is tempting to stave off the problems by banning new graphics calculator technologies from examinations, and hence from schools, this is likely to merely exaggerate the problems of making sound educational decisions at a later time. In addition, we are not likely to learn much about the actual effects of the new technologies in schools and universities once they have been banned. A good example of this concerns the use of programmable scientific calculators, which were rarely allowed into mathematics examinations, with the result that we learned very little about their possible uses, most of which are beneficial, for mathematics.

Acknowledgement: Earlier versions of this paper were improved following advice from Marian Kemp of Murdoch University and an anonymous reviewer, to both of whom I am grateful.

References

Casio 2000 *Activities and program resources*
[http://www.casio.co.jp/edu_e/resources/add_in/] 20 August 2000.
College Board 2000. *2000-2001 list of graphing calculators*.
[http://www.collegeboard.org/ap/calculus/html/exam007.html] 17 August 2000. (a)
College Board 2000. *Use of graphing calculators in AP calculus*
[http://www.collegeboard.org/ap/calculus/html/exam002.html] 17 August 2000. (b)

College Board 2000. *Advanced Placement Program course description: Calculus AB, BC (May 2000, May 2001)*, College Board. [http://www.collegeboard.org/ap/library/pdf/ap_calculus00-01.pdf] 17 August 2000. (c)
Curriculum Council of Western Australia 2000. *Approved calculators* [http://www.curriculum.wa.edu.au/pages/student/student04p.shtml] 20 August. (a)
Curriculum Council of Western Australia 2000. *Assessment support materials/mathematics.* [http://www.curriculum.wa.edu.au/files/pdf/34288_1.pdf] 21 August 2000. (b)
Goldenberg, P. 2000. *Finding some "common notions" about technology in mathematics learning.* Unpublished paper presented at the 9th International Congress on Mathematics Education, Makuhari, Japan.
Herget, W., Heugl, H., Kutzler, B. & Lehmann, E. 2000. Indispensable manual calculation skills in a CAS environment. [http://www.kutzler.com/article/art_indi/indisp.htm] 21 August.
Heid, M.K. 1988. Resequencing skills and concepts in applied calculus using the computer as a tool. *Journal of Research in Mathematics Education*, *19*(1), 3-21.
Kemp, M., Kissane, B., & Bradley, J. 1996. Graphics calculator use in examinations: accident or design? *Australian Senior Mathematics Journal*, *10*(1), 33-50. [http://cleo.murdoch.edu.au/asu/learning/pubs/mkemp/asmj96.html]
Kennedy, D. 1995. Climbing around on the tree of mathematics, *The Mathematics Teacher*, 88, 6, 460-465. [http://partners.mediacentre.com/grade9math/articles/tree.pdf]
Kissane, B. 1999. The algebraic calculator and mathematics education. In W-C Yang, D. Wang, S-C. Chu, & G. Fitz-Gerald (Eds) *Proceedings of 4th Asian Technology Conference on Mathematics*, (pp 123-132) Guangzhou, China, Asian Technology Conference in Mathematics. [http://wwwstaff.murdoch.edu.au/~kissane/papers/ATCM99.pdf]
Kissane, B. 2000. *Programming your calculator: Casio fx-7400G PLUS*, Sydney: Shriro.
Kissane, B., Kemp, M. & Bradley, J. 1996. Graphics calculators and assessment. In P. Gomez & B. Waits (Eds) *Roles of calculators in the classroom*, (Electronic proceedings of Topic Group 18), 8th International Congress on Mathematics Education, Seville, Spain. [http://ued.uniandes.edu.co/servidor/em/recinf/tg18/ArchivosPDF/Kissane.pdf]
Kissane, B., Bradley, J., & Kemp, M. 1994. Graphics calculators, equity and assessment. *Australian Senior Mathematics Journal*, *8*(2), 31-43. [http://cleo.murdoch.edu.au/asu/learning/pubs/mkemp/asmj94.html]
Kutzler, B. 1996. *Improving mathematics teaching with DERIVE*. Bromley, UK: Chartwell-Bratt.
Leinwand, S. 1994. Four teacher-friendly postulates for thriving in a sea of change. *The Mathematics Teacher*, *87*(6), 393-5.
Ralston, A. 1999. Let's abolish pencil-and-paper arithmetic. *Journal of Computers in Mathematics and Science Teaching*, *18*(2), 173-94.
Stacey, K., McCrae, B., Chick, H., Asp, G. & Leigh-Lancaster, D. 2000. Research-led policy change for technologically-active senior mathematics assessment. In Bana, J. & Chapman, A. (Eds.) *Mathematics education beyond 2000.* Proceedings of the 23rd annual conference of the Mathematics Education Research Group of Australasia (pp 572-579) Perth: MERGA.
Texas Instruments 2000. *What is Flash?* [http://www.ti.com/calc/docs/sdk_article_flash.htm] 21 August. (a)
Texas Instruments 2000. *TI-83 Plus software* [http://www.ti.com/calc/flash/83p.htm] 20 August. (b)
Waits, B. K. & Demana, F. 2000. Calculators in mathematics teaching and learning: Past, present and future. In M. J. Burke & F. R. Curcio (eds) *Learning mathematics for a new century: 2000 Yearbook* (pp 51-66) Reston, VA: National Council of Teachers of Mathematics.