Graphics calculators in the mathematics curriculum: Integration or differentiation?

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Graphics calculators are examples of powerful technologies that we want our students to learn to use well. However if we use them in our courses only for learning, students will not regard them with due importance because they are not integrated into the assessment. On the other hand, if graphics calculators are integrated into both learning and assessment there are risks associated with students becoming calculator dependent, issues of equity arise associated with calculator access and there may be problems with setting an appropriate examination. We discuss this dilemma in the light of our experiences and the reactions of our students over the last two years.

Introduction

This paper outlines the dilemma between partial and total integration of technology into the curriculum. It is based on our experiences of using graphics calculators in a first year tertiary mathematics course for non-mathematics specialists. One of the major problems associated with introducing a new form of technology into a course is deciding the extent to which it should be integrated. Should it be used only in the teaching and learning processes or should it be used in some or all of the assessment tasks including assignments, tests and the final examination? Full integration into a course is almost impossible where computers are being used but for graphics calculators the options are more flexible. In 1994 we decided that graphics calculator use would be allowed in an undergraduate mathematics course but only in tutorials, for study and in one of the three tests However, in 1995 graphics calculators were fully integrated into all aspects of the course including tutorials, private study, assignments, tests and the final examination. The dilemma concerning the extent of integration of graphics calculators into a course has been a real one for us, and the concerns expressed in this paper are ones that we have discussed extensively.

The need for integration

There are many arguments for the incorporation of technology into all aspects of a course, including assessment. These include arguments related to curriculum development, equity of access and the acquisition of skills in using technology. Some of these issues have been discussed elsewhere (Kissane, Kemp & Bradley 1994; Kemp & Kissane 1995). However, we now have the results of student surveys that back up the arguments.

In our technological age it is desirable for students to complete mathematics courses not only with mathematical understanding but also with some expertise at using current technology. Appropriate curriculum development should then enable students to essentially learn more mathematics than was possible in the past. For example, a pre-calculus course might have included the solution of equations provided the equations were linear or quadratic or contained polynomials with very obvious factors. However, once the basic relationships between the solution of an equation and the graph of a function are learnt, approximate solutions to complicated polynomial, rational, logarithmic, exponential and trigonometric equations are readily obtainable using a graphics calculator.

Whilst the mention of equity of access may immediately bring to mind arguments related to students being unable to afford calculators and consequently having very limited access, there is another issue. This is associated with denying students access to technology and its subsequent effect upon, amongst other things, employment prospects. More and more employers are using technology to streamline their work and expecting prospective employees to be fully equipped to handle the technology. Whilst the technology used in the workplace may not be identical with that previously used, a student who has come to grips with one particular form is less likely to be hesitant about using another. If technology is integrated into a course, all students will necessarily have access, but if it is optional then only some will.

Graphics calculators are complex devices and time needs to be devoted to learning to use them well. If they are integrated into a course then it is necessary that time be allocated to learning to use them. It is our experience that the learning curve with graphics calculators can be a steep one. Appropriate basic tuition provides a platform from which the students can take off and explore. Unfortunately, if the technology is seen as an optional extra, rather than an integral part of the course, then the basic learning will not go as far as it could and many students are less likely to develop effective skills.

When technology is not totally integrated into all aspects of the course, including assessment, and in particular in the final examination, it has been our experience that teaching and learning are not as effective as they might be. This view is supported by the results of our student surveys in 1994 and 1995. The percentages of students in favour of using the graphics calculators changed significantly between 1994, when calculators were only used in some parts of our course, and 1995 when the calculators were fully integrated, as can be seen in the extract from the survey results below:

Survey Results (Percentage of students either agreeing or strongly agreeing to the statements)	**1994**	**1995**
Overall I enjoyed using the graphics calculators.	69%	87%
Using the graphics calculator helped me to understand the relationship between graphs and solutions to equations and inequalities.	71%	87%
Some assignment questions should require the use of graphics calculators.	68%	86%
It was a good idea to be able to use the graphics calculators in the test.	76%	96%
I think that we should be allowed to use graphics calculators in the final examination.	54%	87%

We had been very pleased by the positive response to the graphics calculators indicated by the 1994 survey. However, the even more positive responses in the 1995 survey confirmed our belief in the necessity of total integration of the technology into all forms of assessment in order to maximise the teaching and learning benefits. A more detailed account of student reactions to the 1994 experience is given in Kissane, Kemp & Bradley (1995).

As well as the kinds of questions above, there were opportunities for students to make written comments on any part of the course. Some comments in the 1994 survey indicated reservations about spending time learning how to use the graphics calculators since they were not permitted to be used in the final examination. Many indicated that they thought it would be a good idea to use them in the final examination, although some had reservations as to the extent of the use. Two examples of such comments were (exactly as written) :

> I thought the graphics calculators didn't give me as much as I could get from them. We should be allowed to use the calculators (graphic) and normal ones in a test together.

> Graphics calculators did assist in many ways especially to provide quick and easy checks on your working. However if the calculator is to be integrated into the course as it is (ie having the test) I believe it should be available in the exam ...

Comments like these, the favourable percentages above and many informal comments made by students during 1994 gave us sufficient incentive to attempt integration of the calculators into all aspects of the course in 1995.

The risks of integration

On the other hand, despite the positive effects expected and obtained, there are risks and potential problems associated with integrating graphics calculators into a mathematics course. Students may become dependent upon their calculators; inequities may arise from different levels of access to calculators or from access to calculators of different capabilities; and it may prove to be too difficult to design appropriate assessment measures.

Concerns about calculator dependency are certainly not groundless. Many secondary school mathematics teachers report that their students use calculators in situations where other ways are expected and preferred, and some students will even admit to reaching for a scientific calculator to deal with an arithmetic problem before they consider alternative ways of addressing it. Observations of similar kinds are readily made with respect to undergraduate students, especially with aspects of mathematics that they find difficult (such as fractions, percentages and negative numbers). Indeed, a common reason given by primary school mathematics teachers for not allowing children to use calculators is that teachers are concerned that students will not learn the important mathematical skills, often referred to as 'the basic skills', if access to calculators is too readily available. With such a tradition of concern for calculator dependency, it would indeed be surprising if undergraduate teachers did not share similar fears. The view of the graphics calculator reflected in this kind of reservation is that of a cheating device, one of the metaphors described by Kissane (1995).

Many concerns about calculator dependency expressed by secondary mathematics teachers are essentially concerns about arithmetic - the operations of addition, subtraction, multiplication, division and powering of whole numbers, fractions, decimals and percentages. However, the mathematical stakes are raised somewhat in the case of the graphics calculator, since much more than mere arithmetical calculation is involved. The very power of the graphics calculator to do so much more than arithmetic heightens the unease mathematics teachers may have about the advisability of integrating them. Drawing graphs of functions, solving equations, manipulating matrices, locating important points on graphs, approximating numerically derivatives or integrals and analysing statistical data have generally required more mathematical background than is now the case with a graphics calculator. Fears that students will take the easy way out and develop the (calculator) manipulative skill without adequate conceptual underpinning are understandable. Some students even expressed such a fear:

> I don't think they should be used in the exams (only exams that are particularly focussed on the TI-82) because maths is about using your understanding and perception and perhaps this ability will become obsolete if the calculator takes over, just as I'm unable to do simple sums without the calculator now ...

A second reservation about integration concerns the potential for students to have different levels of access to appropriate technology. Differences between graphics calculators are substantial, as might be expected with products that range in price today from around $80 to more than $240. It is possible that allowing students to use graphics calculators in a mathematics course may inadvertently confer an advantage on students with access to more financial resources. It seems likely that all students in a course will be using a similar graphics calculator, for practical reasons for the next few years. Even in such situations, inequities can arise. For example, the students who are able to afford to buy their own calculator, which they can use more often and become more adept with, are advantaged over the students who are obliged to rely on the access provided by a class set or by graphics calculators available for loan in a library.

A third reservation about the integration of graphics calculators into a mathematics course concerns examinations, and can be regarded as an outgrowth of each of the previous two reservations. It is still the case for many undergraduate mathematics courses that final examinations are regarded as the main form of evidence of student learning, or the lack of it, despite ample evidence of the unfortunate side-effects of examinations on students and their teachers. In many tertiary institutions, it is regularly the case that mathematics examinations are given close to the full weighting allowed, rather than the bare minimum tolerated, a phenomenon less likely to be observed in most other parts of universities. It has never been easy to design mathematics examinations to elicit credible evidence of conceptual student learning, rather than just routine repetition of standard procedures. It is even harder to distinguish between deep and surface learning when students have powerful graphics calculators at their disposal and the problem is also complicated by students having access to calculators with different capabilities. Many of these concerns are addressed by us elsewhere (eg., Bradley 1995; Kemp, Kissane, and Bradley 1995; Kissane, Bradley, and Kemp 1994).

Towards a resolution

By their nature, dilemmas cannot be resolved. However, we offer below a few observations to contribute to a discussion of this particular dilemma.

The first concern about integration in this paper is that of calculator dependency. Students do need to be able to make sensible decisions about when to use or not use a calculator. Teaching students how to make good choices may well reduce their dependency on the calculators. This needs to be addressed explicitly in connection with all aspects of a course including studying, tutorial work, assignments, tests and examinations. The appropriateness of the use of the calculators in different contexts varies considerably and students should be encouraged to build up an awareness of the need to think about that appropriateness before reaching for the calculator.

The second area of unease is related to issues of access and equity. These cannot be resolved completely but with the steady reduction in price more students will be able to buy their own graphics calculator, rather than having to rely on borrowing one. The wide range of capabilities of graphics calculators has also caused concern in terms of equity. However most work at the secondary and first year tertiary level is done at the lower end of graphics calculator capabilities, where the differences are less important, and less sophisticated calculators can be programmed to ensure that students are not disadvantaged.

The third reservation is concerned with examinations. Generally speaking the examination mark comprises a large proportion of the total assessment and as such is a major concern. There seems to be limited expertise worldwide concerning the setting of examination papers where graphics calculators are allowed and many examinations that are being set are 'calculator neutral' papers. However, it is feasible to design an examination paper which allows the use of a graphics calculator, but which does not compromise important course objectives. A detailed discussion of the issues of examination design and graphics calculators can be found in Kemp, Kissane, and Bradley (in press).

As with all dilemmas, we need to weigh up the pros and cons. But practical educational decisions still need to be made. Having considered the arguments carefully we would suggest that the integration of graphics calculators into all aspects of the curriculum, including assessment, is a more appropriate decision than differentiating between those parts of the course in which the technology can be used. Our experience suggests that the problems associated with calculator dependency, equity and examinations can be reduced by careful organisation. However, the negative effects of permitting the use of calculators in only some parts of a mathematics courses are more difficult to counteract.

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Please cite as: Bradley, J., Kissane, B. and Kemp, M. (1996). Graphics calculators in the mathematics curriculum: Integration or differentiation? In Abbott, J. and Willcoxson, L. (Eds), *Teaching and Learning Within and Across Disciplines*, p21-25. Proceedings of the 5th Annual Teaching Learning Forum, Murdoch University, February 1996. Perth: Murdoch University. http://lsn.curtin.edu.au/tlf/tlf1996/bradley.html

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This URL: http://lsn.curtin.edu.au/tlf/tlf1996/bradley.html
Last revision: 12 Apr 2002.
Previous URL 20 Dec 1996 to 12 Apr 2002 http://cleo.murdoch.edu.au/asu/pubs/tlf/tlf96/bradle21.html