Measuring the Degree of Technology Use in Tertiary Mathematics Courses

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Abstract: This paper reports on a significant development of a larger study currently being undertaken into technology and curriculum change. Many proponents of the use of technology in mathematics education argue that to be effective, such usage should be fully integrated into all aspects of the curriculum, but exactly what is meant by *integrated technology* is seldom clearly defined. A number of tertiary mathematics teachers were surveyed to investigate the degree to which technology is used in their courses, and the information received was used to identify several aspects critical to an examination of integrated technology. This paper then proposes a model to aid in the description and comparison of technology integration in different courses.

1. Introduction

The author of this paper is currently engaged in a wider study investigating the factors that facilitate and impede the response of tertiary mathematics curricula to technological developments. One necessary requirement of this wider study is the ability to measure and compare the current level of technology use in the mathematics courses under investigation. The need to quantify the extent of technology use is also clearly indicated in the literature, where frequent references are made using such descriptions as *integrated technology* (e.g. see Kissane, [1] and Kawski, [2]), but seldom are such terms clearly defined. Indeed, most often the ensuing description is more about how technology has been simply incorporated into the existing curriculum as an additional functional tool, with little subsequent change to the overall curriculum. It seems the term *integrated* is most often used to evoke ideas that are expected to be universally understood at some vague intuitive level, without attempting to rigorously define what is meant by the term.

This paper reports on an initial investigation to establish a means of quantifying the level of technology use in tertiary mathematics courses. Firstly, a means is sought to determine exactly what is meant by the description of integrated technology as used in the literature. These findings are then used to construct a model that may be used to measure and compare the degree of technology integration within and between courses.

2. Basis for the Study

Most mathematics instructors have at some time imagined themselves teaching in their perception of an ideal learning environment. Such an environment might well be of a constructivist [3], or perhaps more recently an enactivist [4] nature, would most certainly have a small number of students, would be free of the imperatives of national curricula and the pressures of narrow, assessment driven syllabi, and would not have any financial restrictions on resources, such as course texts and access to technology. While there would probably be common agreement about many such attributes of an ideal learning environment, for example, small class sizes and no financial limitations, the debate over the relative merits of the use of technology is by no means exhausted. There are still many instructors who would not include technology in their ideal teaching environment, and this is especially true in the tertiary sector where this study is focused. Indeed, there is considerable variation between tertiary institutions within New Zealand and internationally with respect to the acceptance and use of technology in the teaching and learning of mathematics. This is most clearly evident in early undergraduate courses, where some mathematicians favour at most only limited use of technology in their teaching, believing, for example, that the use of calculators and/or computers may impair students' development of basic mathematical and cognitive skills. Despite such opposition, there is growing support in the literature for technology use at the tertiary level, as noted by Oates and Thomas [5], when they observe that although the great majority of studies into technology are focused at the secondary level, there is now a growing body of research at the tertiary level demonstrating that technology may be of substantial assistance pedagogically, with particular benefits in developing students understanding of concepts (e.g. see Hollar & Norwood, [6] and Hong & Thomas, [7]).

With respect to technology and curricula change however, the situation is much less well-documented, and again, where they occur, most studies are principally focused at the secondary level. Anthony [8] notes that studies at the tertiary level make up only a small proportion of all MERGA studies and that this figure is diminishing (from nearly 18% in 1994 to 5% in 2003). She cites Wood (in press) to support the claim that this trend is an enduring one ([8], p. 8). This is further compounded if one considers the observation that in the 2003 MERGA proceedings, studies of both technology (10%) and curriculum (5%) are also under-represented (Anthony, [8], p. 5). The situation is little better in forums focused on the tertiary sector such as Delta, which comprises a biannual gathering of some 120 leading tertiary mathematics educators and mathematicians from many international institutions, predominantly from the Southern Hemisphere. An inspection of the Proceedings of the Delta '03 symposium on the teaching and learning of undergraduate mathematics held in Queenstown, New Zealand reveals that although technology studies are much better represented (11 of 57 articles directly associated with technology), only three of these make specific reference to curriculum issues and none of these has curriculum as its primary focus (see [9] and [10]). Arnold [11] notes that in an extensive worldwide review of handheld graphing technology commissioned by Texas Instruments in 2002, the focus of the 43 studies finally reported on was almost entirely focused at years 10-12 (p. 20). In another earlier meta-analysis of graphics calculator research, Penglase and Arnold [12] reviewed several articles that examined curricula issues, (e.g. see in [12]: Boers & Jones, 1992; Jost, 1992; Zammit, 1992), but after considering these studies, Penglase and Arnold [12] concluded that there is a particular need for more specific studies into technology and the curriculum when they note that:

> …(the majority of) those studies which purported to investigate curriculum issues…have been seen to be instead studies of pedagogy, as the use of the tool remained intertwined with the effect of the learning context. Of more benefit, then, may be those studies, which directly attempt to address the issues of graphics calculator use within particular learning environments. (p. 79)

Arnold [12] believes the above observation in 1996 has changed little in 2004 when he states with respect to CAS-calculator technology (calculators with computer algebra capabilities), that:

> Even today, there remain widespread reservations regarding not only the best ways to incorporate such tools into teaching and learning, but fundamental questions regarding their appropriateness…The questions which practitioners have been asking (*What will be left to teach if students have access to tools which factorise, solve, and do calculus? What about their manipulative skills? What will we ask them to do in examinations?*) were the same questions asked a few years ago regarding graphing calculators. In fact, they were precisely the same questions asked twenty years ago regarding student access to traditional calculators. (p. 21)

It is possible however to identify from the literature several features which are commonly associated with the notion of *integrated technology* that will be useful in guiding this investigation. Leigh-Lancaster [14] suggests three such features in his concept of *congruency* between curriculum, pedagogy and assessment with respect to CAS-calculator technology, arguing that CAS should be specified in the curriculum, actively used in the classroom, and expected in examinations. Assessment is one area that is frequently discussed in the literature, especially with respect to the exclusion or inclusion of technology in final exams (e.g., Kissane et al, [15] and Kiernan et al, [16]). The argument for the inclusion of technology in all assessment is neatly described in the following excerpt.

> We need new ways of evaluating student learning which has been accomplished with calculators and computers. For example, it makes little sense to use calculators and computers to express algebraic concepts graphically, then examine students with tests that do not include graphical representations. (Dugdale et al, [17], p. 351)

In their report on the implementation of CAS-calculators into a first year calculus course at The University of Auckland, Oates and Thomas [18] identify several other factors discussed in the literature that seem significant in discussing integration of technology. They cite Tucker and Leitzel (1995) for example, who observe that little curriculum change has occurred in many United States institutions reporting the use of technology as part of the calculus reform movement, with most courses just adding technology into existing curricula, resulting in unwieldy courses. Stacey, Asp & McCrae [13] observe that CAS necessitates a change of methods taught, as well as providing an opportunity for change. In relating curriculum change to pedagogy and student facility, Kawski [2], in a paper discussing the use of MATLAB and MAPLE observes that

> …some of the most distinctive features of computer algebra systems and numerical packages are their implementations of the concept of a function. When thoughtfully matched and integrated into the curriculum these realisations may be extremely helpful…On the other hand, thoughtless use of either kind of package may cause more confusion, more harm than good. (p.168)

Kutzler [19] further stresses the need for appropriate use of the technology when he cites Heugl, who said that "…if it is not (pedagogically) necessary to use an algebraic calculator, it is (pedagogically) necessary not to use (it)" (p. 5). With respect to access to technology, Barton and Oates [20] note that when the technology is optional, few students will take up the opportunity, regardless of encouragement, whilst Zevenbergen [21] has considerable concerns about equity if technology is made compulsory. Oates and Thomas [18] identify one further feature when they raise concerns about training in the use of the calculators for both staff and students.

Several other sources also offer insight into factors that should be considered in any potential taxonomy of an integrated-technology course. Thomas and Holton [22] discuss the intended versus the implemented curriculum, and they view Hoyle's (1998) list of obstacles to the successful implementation of technology as having significant implications for achieving integration, namely:

- Limitations on access to technology
- Lack of time for students and staff to familiarise themselves with the technology
- Being technology centred instead of mathematics centred
- Delivery by technology as if by a lecturer
- Emphasis on calculation versus explanation and reflection

(Hoyle 1998, in [22], p. 384)

Engelbrecht and Harding [23] give a lengthy description of their attempts to categorise and develop a taxonomy for web-based learning of mathematics, and much of the process they use, and their resultant descriptions is either directly applicable or may be usefully adapted to the discussion of technology integration. They cite, for example, Harmon and Jones' (1999) classification of five levels of the amount of web use in education, and three of these, *supplemental, essential,* and *immersive* suggest a possible means of assessing the degree to which technology is integrated into a course. Supplemental and immersive, for example, may be used when considering pedagogical factors, such as describing a course where the teachers use the technology solely as a demonstration tool, almost like an advanced, dynamic overhead projector (supplemental) compared to a course where the students all possess and interact frequently with the technology (immersive), whilst essential could be used to describe a course where technology is compulsory, expected, and required to succeed in the course. Several of Engelbrecht and Harding's [23] later categorisations appear even more very useful and adaptable in the discussion of integration, namely *Dynamics and Access, Assessment, Content* and *Richness.* The many features of interest in examining *integrated technology* identified in this discussion were then used to help formulate the questions asked in the survey, and the development of the taxonomy of integrated technology which are detailed next.

3. A Survey of Technology Use

The wide international representation of delegates at the 2003 Delta forum suggested a highly appropriate and easily accessible means of gaining a useful picture of technology use in tertiary mathematics courses. The selective nature of this group is acknowledged, but since this investigation aims only to determine a means of assessing and comparing actual technology use, not draw any conclusions about teachers' support or opposition for such usage, the effects of any potential bias are considered minimal. Features of interest in discussing integration of technology identified in the review of the literature were used to inform the construction of a short questionnaire and this was sent to 102 of the delegates from the Delta '03 symposium for whom email addresses were readily available. An introductory paragraph described the nature of the study and explained that the definition of "Technology" used here referred to specifically mathematics-enabling technology, for example graphics calculators and CAS-calculators and computer software, not more general technology such as web-based delivery and video-tapes. Teachers were first asked to identify the type of technology used, the course it is used in, and why they used the particular technology chosen for their course. Then they were asked a series of questions to determine the nature of their technology usage, namely: How is it used in assessment? What access do students have to the technology? Is it compulsory? How do teaching staff use the technology in their teaching? What assistance is there for both staff and students in learning to use the technology? What changes if any were made to the curriculum/course content to reflect the use of technology? In addition, they were asked a more general open-ended question asking them to comment on what they understood is meant by the description of integrated technology. 31 individual responses were received from tertiary mathematics and statistics teachers, representing 21 different institutions and 5 countries (often more than one course from each institution).

Space prevents a full presentation of the responses to the survey in this paper, but an inspection of the data does provide an excellent picture of the wide variation in technology use that exists between institutions, both within and between countries. For example, one institution in the United States reported intensive use of technology in all its first year courses, an extremely high rate of individual ownership of calculators, and permissible and expected use in all assessment including examinations. By way of contrast, another institution, in New Zealand, reported only optional use of solely graphics calculators in its primary first year course, with student ownership at about 10%, and examinations that are written to be *calculator-neutral* so as to give no distinct advantage to students with calculators. The type of technology used, and the courses for which technology was allowed also varied greatly. For example, the use of computer-based applications in such applied courses as engineering mathematics and statistics was commonly accepted, but much less so in core advancing mathematics courses, while some used graphics calculators, but not CAS capable machines such as the TI-89 or TI-92. Six respondents had no experience with the use of technology in courses they had taught, and although these responses are not reported on here since we are concerned principally with comparing courses which use technology, their responses will certainly be pursued in the wider study from which this paper originates. For example, one respondent's unsolicited explanation of his non-use of technology that "…(my) view of graphics calculators is rather a negative one. I consider them to be obsolete now tools such as Excel are available" certainly warrants further investigation when examining the type of technology chosen to be used in a course. The survey data reinforced the features of technology use identified previously in the review of the literature that could be used to distinguish between courses. Table 1 summarises the responses received to one question from the survey according to four categories derived from an analysis of the responses. A similar analysis to that displayed in Table 1 was carried out for each question asked in the survey, with the categorisation of the type of response for each feature being extracted from an analysis of the range of responses, as well as being informed by the literature.

Table 1 Technology Use in Assessment in Tertiary Institutions

Sample Survey Question	Category of Response	Number	Typical Response or Comment
Is technology permitted/expected in assessment?	All, assessment requires technology (technology-active)	12	"We write the exams assuming students have a graphics calculator"
	All, but assessment is technology-neutral	5	"Can't disadvantage the students without a graphics calculator"
	Some, e.g., not exams.	5	"The final exam is not in a computer laboratory"
	All except special technology free section (usually skills)	2	"We include a compulsory skills component in the exam where calculators are not permitted"

The categorisation of the all the data from the survey, as depicted in Table 1 for one of the questions (Is technology permitted/expected in assessment), was then used to develop a taxonomy of integrated technology, which is described next.

4. A Taxonomy for Integrated Technology

Responses to the final open question in the survey reinforced the difficulty in defining the concept of integrated technology. Many of the responses resorted, as has the author frequently in discussions, to using such statements as "the technology must be integral to the course", or other terms such as "essential" to describe what is required. Whilst these terms do conjure up a picture of what is meant, a more definite means of quantifying the degree of integration is required if valid comparisons are to be made between courses, and any inferences about the importance of technology integration are to be made. The categories of technology use gained from analysing the survey responses described in the previous discussion were compared to those from the literature described earlier, for example Leigh-Lancaster's concept of congruency [14], Hoyle's obstacles to successful implementation [22], and Engelbrecht and Harding's taxonomy for web-based mathematics learning [23]. From this comparison, six defining characteristics were identified that broadly describe the extent of the use of technology in a course. For example, issues concerned with how students accessed the technology, ranging from tutorials in a computer laboratory through to compulsory purchase of a CAS-calculator, are broadly categorised under *Access*. Time for both staff and students to familiarise themselves with the technology, staff professional development, and what assistance is provided for students in learning the technology, e.g. technology-specific tutorials and/or course notes and examples, are included under the respective categories of *Staff Facility* and *Student Facility*. Considerations under the characteristic *Assessment* are largely as outlined in Table 1, along with issues identified in the literature (see [15], [16] and [17]). While there is some overlap in the categories, e.g. issues of assessment and pedagogy are clearly also curriculum considerations, the survey data and the literature suggested sufficient basis for categorising these separately. All six characteristics are summarised in Table 2 below as a suggested taxonomy for an integrated-technology course. Table 2 also gives an indication of what is being measured with respect to each characteristic, in the examples of the sort of questions that may be asked to examine the degree of integration associated with each characteristic.

Table 2 *A Taxonomy for Integrated Technology*

	Characteristic	Example of question asked to examine each characteristic
A	Access	To what extent do students have access, e.g. is it compulsory?
B	Student Facility	How facile are students with the use of the technology, and what assistance is provided to help them?
C	Assessment	Is technology expected and/or permitted in assessment?
D	Pedagogy	How and when do the staff and students interact with the technology? For example, is it used mainly as a complex calculation device and demonstration tool, or to develop and explain concepts?
E	Curriculum	Has the course curriculum, for example content, order of teaching, changed to reflect the use of technology?
F	Staff Facility	Are staff familiar with the use and capabilities of the technology?

A means of measuring the extent of integration for each of the items in the taxonomy detailed in Table 2 will now be considered in a comparison of two courses in the survey from a technology perspective.

5. A Comparison of Technology Use

Given the extreme variation indicated in the survey in the style of technology used, and the differences in the type of course in which that technology was incorporated, finding a suitable means of comparing technology usage between courses presents a real challenge. How for example may we compare the degree of integration between the following two first year calculus courses? The first has full access to high calibre computer laboratories and computer-based assignments, but prohibits the use of technology in examinations. The second uses CAS-calculators actively in teaching, and their use is encouraged in all forms of assessment, but they are only optional for students to buy. Subsequently only about 10% of the students own them. Sometimes, the decision about which technology to use reflects the availability of a given technology and decisions about student access, for example cost, sponsorship from industry, or in the case of several United States institutions, the decision to use graphics calculators because nearly all students own them. Other times, the decisions are made on pedagogical grounds. One example is the use of particular computer-based statistical packages because they are widely used in the commercial and research fields, another is not allowing CAS-calculators in first year calculus courses because they may impair a student's learning of vital algebraic skills. These examples suggest that any description of integrated technology should include a consideration of the factors influencing decisions about the type technology used (e.g., access, pedagogy), but still allow if possible for a comparison between courses that is independent of which technology is ultimately used. The data from the survey also suggests that valid comparisons may be possible only between courses of a similar nature, e.g. comparing two first-year statistics courses would be possible, but not a second-year course with a first-year. For example, it is reasonable to expect that students in a second-year course may already have a reasonable level of facility with the technology from previous use in first year courses, so the *student facility* imperatives differ in such cases. Similarly, an applied mechanics course may contain a pre-requisite for a particular software use that makes it radically different to a more traditional pure calculus course that has more options as to which if any technology it uses.

Engelbrecht and Harding [23] encountered similar difficulties when attempting to characterise on-line mathematics courses, noting that "it is difficult to compare the scope and extent of any two online courses because both might be lacking in certain, not necessarily the same, aspects and exceed again in other, different, aspects" (p. 9). They proposed a strategy for comparing the components of the course identified in their taxonomy, by assigning each component to the radial of a radar chart, with an associated quantifying measure. The subsequent diagrams provided a very effective visual means of comparing the extent of internet utilisation, and promised a similarly effective strategy for technology integration. The two first year calculus courses described above will be used to explore this strategy. The survey responses for each course were compared against the six characteristics identified in the taxonomy in Table 2. Each characteristic was assessed on a 5-point scale assigned by the author from the survey responses according to matching levels of technology integration for the given characteristic. A grade of 5 would indicate a high (full) level of integration, a grade of 1 a low level. Quantifying the factors did prove somewhat problematic, and it became clear during this process some of the assignations of values (on the five point scale) were somewhat subjective. In hindsight, it may have proved more rigorous to ask the respondents to assign these values themselves, but the taxonomy had not been developed at the time the survey was conducted. More radials may also help to give a fuller description, for example to help distinguish between the staff and student aspects of the pedagogical component, and to examine the resources and constraints of the technology. Certainly more work is needed to develop a more robust relationship between each taxonomy component and its numerical assignation. A full description of the technology use associated with every value on the 5-point scale proposed for each component is not possible here, but an example of two of the radials is given so the information displayed in the radar charts can be reasonably judged. For example, Institution A was assigned a maximum value of 5 for the access component (radial A in figure 1), indicating that all students within the course had their own graphics calculators, and that this was both expected and necessary. Institution B was assigned a value of 2, since ownership of the calculators in this course is optional, with only about 10-20% of students possessing one. For assessment (radial C), 4.5 for institution A indicates that the calculators are expected in all forms of assessment, except for a small skills test component of the course upon entry. Institution B receives a 3, since although the calculators are permitted in all forms of assessment, the test and final exam attempt to be calculator-neutral. Similar assignations were made for each of the other characteristics in the taxonomy, and the results are shown in Figure 1 below. The letter on each radial corresponds to the associated characteristic in Table 2.

Figure 1. Comparison of the extent of technology use in two first year tertiary calculus courses.

The area in the radar diagram gives an indication of the extent to which technology is integrated into the course. The shape of the shaded area in the radar charts is also important in characterising the level of technology integration in a course. The right-hand side radials (A, B, C) measure the ability of students to use the technology, that is are they able to access it? Do they know how to use it? Can they use it in assessment? The left-hand side radials (D, E, F) measure the design and delivery of the course, that is pedagogical considerations, curriculum, and staff professional development. There is of course overlap here as assessment issues obviously concern staff as well as students, and students are affected by pedagogical considerations, hence these characteristics are grouped together at C and D on the chart. From an inspection of the charts in Figure 1, it can be seen that both courses are fairly evenly spread in terms of the development of each component of the taxonomy, with Institution A clearly having a much richer level of integration overall. This comparison was much more difficult to discern from an examination of the initial data in the survey responses, and this small case study certainly demonstrates the value of the radar chart structure described in quantifying and characterising the technology integration in tertiary courses. It will be interesting to see how further courses from the survey compare under this system in future investigations.

6. Summary

The survey results reported here provide support for this study's initial assertion about the wide degree of variation that exists in the use of technology in tertiary mathematics courses. It is also obvious from the survey responses, the support in the literature, and general educational and societal trends, that increased use of technology is inevitable, and that we therefore need to urgently address the question of how best to use technology in our courses. Often, discussions about the use of technology refer to integration, when in fact they are more usually describing examples of simply incorporating technology into existing curricula, albeit examples that provide new ways of investigating individual problems, or exciting new uses with specific content areas. These are interesting and useful, but are some way from being considered as what this paper suggests is meant by a fully integrated-technology course. The survey findings are used to develop a taxonomy to define what we mean by the description of a course as technology-integrated, identifying six characteristics that may be used to describe the extent of technology use in a course. The components of the taxonomy are then used to examine two separate courses, with the development of a useful strategy to make appropriate comparisons between courses. As is identified in the discussions, some aspects of the mechanisms used in this study still require further development. For example, the measures used to assess each component of the taxonomy with respect to the degree of integration need to be more rigorously defined, and more comparisons between different courses need to be considered to establish the true effectiveness of the model.

The discussions presented in this paper suggest a highly effective means whereby tertiary teachers may examine their current curricula from a technology perspective. The proposed model may be used to compare existing practise, and ultimately to adapt courses to better reflect the potential pedagogical advantages offered by technological advances, all the time remembering, as Kutzler [19], paraphrasing Shakespeare, so eloquently puts it, that "…calculators and computers are neither good nor bad teaching tools, only using them makes them either"(p. 11).

References

[1] Kissane, B. (2000). Technology and the curriculum: The case of the graphics calculator. In M. O. .J. Thomas (Ed.), *Proceedings of TIME 2000,* (pp. 60-71). Auckland: The University of Auckland and Auckland University of Technology.

[2] Kawski, M. (2003). Functions and operators in MAPLE and MATLAB. In *Remarkable Delta:03 Communications of the Fourth Southern Hemisphere Symposium on Undergraduate Mathematics Teaching and Learning*, (pp. 168-174). Auckland: International Delta Steering Committee.

[3] Simon, M. A. (1995). Reconstructing mathematics pedagogy from a constructivist perspective. *Journal for Research in mathematics Education, 26*(2), 114-145.

[4] Davis, B., Sumara, D. & Luce-Kapler, R. (2000). *Engaging minds: Learning and teaching in a complex world*. New Jersey: Lawrence Erlbaum Associates, Inc.

[5] Oates, G. & Thomas, M. O. J. (2001). Throwing out the bath water? Adapting curricula to reflect changes in technology. In *Communications of the Third Southern Hemisphere Symposium on Undergraduate Mathematics Teaching*, (pp. 79-84). South Africa: SAMERN.

[6] Hollar, J. C. & Norwood, K. (1999). The effects of a graphing-approach intermediate algebra curriculum on students' understanding of function. *Journal for Research in Mathematics Education, 30*(2), 220-226.

[7] Hong, Y. Y. & Thomas, M. O. J. (1996). The Riemann Integral in calculus: Students' processes and concepts. In P. C. Clarkson (Ed.), *Technology in Mathematics Education* (Proceedings of the 19th annual conference of the Mathematics Education Research Group of Australasia, pp. 572-579). Melbourne: MERGA.

[8] Anthony, G. (2004). MERGA: A community of practice. In I. Putt, R. Faragher & M. McLean (Eds.), *Mathematics Education for the Third Millennium: Towards 2010* (Proceedings of the 27th annual conference of the Mathematics Education Research Group of Australasia, pp. 2-15). Melbourne: MERGA.

[9] Thomas, M. O. J. & Oates, G. (Eds.) (2003). *New Zealand Journal of Mathematics: Supplementary Issue.* (Proceedings of Remarkable Delta: 03 Fourth Southern Hemisphere Symposium on Undergraduate Mathematics and Statistics Teaching and Learning). New Zealand: New Zealand Mathematical Society and The University of Auckland.

[10] Barton, B., Oates, G., Reilly, I. & Thomas, M. O. J. (2003). *Remarkable delta: 03 Communications.* (Fourth Southern Hemisphere Symposium on Undergraduate Mathematics and Statistics Teaching and Learning). Auckland: International Delta Steering Committee.

[11] Arnold, S. (2004). Handheld classroom technology. In I. Putt, R. Faragher & M. McLean (Eds.), *Mathematics Education for the Third Millennium: Towards 2010* (Proceedings of the 27^{th} annual conference of the Mathematics Education Research Group of Australasia, pp. 16-28). Melbourne: MERGA.

[12] Penglase, M. & Arnold, S. (1996). The graphics calculator in the mathematics classroom: A critical review of recent research. *Mathematics Education Research Journal, 8*(1), 58-90.

[13] Stacey, K., Asp, G. & McCrae, B. (2000). Goals for a CAS-active senior mathematics curriculum. In M. O. J. Thomas (Ed.), *Proceedings of TIME 2000*, (pp. 244–252). Auckland: The University of Auckland and Auckland University of Technology.

[14] Leigh-Lancaster, D. (2000). *Curriculum and assessment congruence – Computer algebra systems (CAS) in Victoria*. http://www.math.ohio-state.edu/~waitsb/papers/t3_posticme2000/leigh-lancaster.pdf

[15] Kissane B., Kemp, M. & Bradley, J. (1996). Graphics calculators and assessment. In P. Gomez & B. Waits (Eds.), *Roles of Calculators in the Classroom,* (pp. 97-124). USA.

[16] Kiernan, C., Oates, G. & Thomas, M. O. J. (1998). Graphic calculators and mathematics assessment. *SAMEpapers*, 88-106. University of Waikato.

[17] Dugdale, S., Thompson, P. W., Harvey, W., Demana, F., Waits, B. K., Kiernan, C., McConnell, J. W., & Christmas, P. (1995). Technology and algebra curriculum reform: Current issues, potential directions, and research questions. *Journal of Computers in Mathematics and Science Teaching, 14*(3), 325-357.

[18] Oates, G., & Thomas, M. O. J. (2002). Indicators for change: A report on the implementation of CAS calculators into a first year tertiary mathematics course. In Moira Statham (Ed.), *Crossing the Bridge* (Proceedings of the Tenth Australasian Bridging Mathematics Network Conference, pp. 130-139). Auckland: UNITEC.

[19] Kutzler, B. (2000). *The algebraic calculator as a pedagogical tool for teaching mathematics*, http://kutzler.com.

[20] Barton, B. & Oates, G (1997). *Graphics calculators in mathematics two.* Unpublished Report to The Department of Mathematics, The University of Auckland.

[21] Zevenbergen, R. (1999). Equity in Tertiary Mathematics: Imaging a future. In W. Spunde, P. Cretchley & R. Hubbard (Eds.), *Proceedings of the Delta'99 Symposium on Undergraduate Mathematics*, (pp. 18-26). Rockhampton: Central Queensland University.

[22] Thomas, M. O. J. & Holton, D. (2003). Technology as a tool for teaching undergraduate mathematics. In A. J. Bishop, M. A. Clements, C. Kietel, J. Kilpatrick & F. K. S. Leung (Eds.), *Second International Handbook of Mathematics Education,* (pp. 351-394). Dordrecht: Kluwer Academic Publishers.

[23] Engelbrecht, J. & Harding, A. (2003). *Are online learners learning or just online? A status report on the teaching of undergraduate mathematics on the Web.* Plenary address to the Remarkable Delta'03 Fourth Southern Hemisphere Symposium on Undergraduate Mathematics and Statistics Teaching and Learning, Queenstown, New Zealand.