Outcomes and implications of students’ use of graphics calculators in the public examination of calculus

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The paper describes an inquiry into students’ uses of graphics calculators in the Tertiary Entrance Examination of Calculus in Western Australia for 1998, which was the first year that calculators were allowed for the examination. The prevalence of calculator usage and marks allocated for six questions are considered, based on data collected from examination markers. The nature of calculator usage is described, including errors made, based on our perusal of examination scripts and interviews with students, teachers and markers. A comparative analysis of boys’ and girls’ performance, as measured by raw examination scores on the examination for 1995–1998 is given. The results suggest that the main areas of difficulty for students are interpreting graphics calculator outputs and knowing when use of graphics calculators is appropriate or possible. While initial indications are that the effect of introducing the calculators is non-discriminatory between boys and girls, no claims can be made without longer-term analysis.

1. Introduction

Allowing graphics calculators in public examinations is part of the ongoing process occurring internationally of accommodating technology into mathematics curricula. In Australia, graphics calculators have been used in examinations for some tertiary courses for several years [1]. However their introduction for public examinations in the secondary sector has occurred only recently: in the State of Victoria, graphics calculators have been allowed in all Certificate of Education mathematics examinations from 1997 and in Western Australia candidates for Tertiary Entrance Examinations (TEE) in mathematics were allowed calculators from 1998.

This paper reports the results of an inquiry into the prevalence and nature of student use of graphics calculators in the 1998 West Australian Calculus TEE.

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The purpose of the inquiry was to explore the implications of students’ calculator usage for teaching and assessment.

2. Background

In Western Australia, Calculus is a Year 12 secondary-school subject that is studied in the second year of a two-year tertiary entrance programme. Most students who were candidates in the 1998 Calculus TEE would have either owned a graphics calculator, or had long-term access to one through school borrowing schemes for the two years leading up to the examination. Graphics calculators without symbolic processing and the Hewlett Packard HP38G with limited symbolic processing were approved. In contrast, calculators with non-symbolic capabilities only were allowed for the Victorian Certificate of Education for 1998 [2] and the policy for the similar standard US Advanced Placement (AP) Calculus examination [3] was to state the minimum level of capabilities assumed in setting questions, but to allow full symbolic capabilities.

A non-prescriptive approach was taken for the Calculus TEE with regard to the working required for calculator-assisted answers. The only instructions were: ‘Incorrect answers without supporting reasoning cannot be allocated any marks. If a question contains the words “show analytically”, this means that you should use methods from the calculus’. These instructions were on the cover of the examination paper, which was distributed to all schools prior to the examination. In comparison, the policy for the US AP Calculus is to require the setup only for definite integrals, equations, or derivatives, but to otherwise require the mathematical steps that lead to an answer [3].

For the three hour 1998 Calculus TEE no explicit instructions were given to use a graphics calculator. Calculator usage was at the students’ discretion with the exceptions that two-part questions specified an analytical approach and one question could not be solved without using the technology. There was no requirement to clear memories of the calculators before the examination and so stored programs and text could be used. Two approved graphics calculators and any number of scientific calculators were allowed and, because the text storage capacities of the various brands of graphics calculators differ, students were permitted four A4 pages (two sheets) of notes.

3. Method

3.1. Data generation

Prior to the examination we selected six out of the nineteen questions from the examination paper that satisfied the criteria ‘Graphics calculators are expected to be used . . . . Graphics calculators are expected to be used by some students but not by others’ [4]. We submitted a proforma for data collection to the Curriculum Council of Western Australia who administer the examination. For each of the six questions examination markers were asked by the Curriculum Council to record the part marks awarded for answers and to circle the methods students used from a list of choices. Systematic sampling [5] of the scripts of the first two candidates listed on each normal marks recording sheet resulted in 404 (21%) out of the total 1882 scripts being selected.

Qualitative data were obtained from four sources. First, 172 (9%) of the 1882 examination scripts were perused to ascertain the details of students’ working.
These scripts were all papers in six randomly assigned bundles of scripts, bundled for marking and assigned randomly to us as examiners and markers. Students were asked, and most complied with the request, to write the brand of their calculator on their script. All commonly used brands of calculators allowed for the examination were represented in the perused scripts. Second, three female and three male examination candidates were interviewed in the week following the examination. The students were chosen on the basis of differing abilities, based on their internal school assessments for Calculus for the year. The paper was used as a heuristic for the interviews, which had the purpose of ascertaining students’ calculator use not apparent in written answers. Third, two teachers of Calculus in 1998 were interviewed after their having worked the examination paper. They were asked how they had used, and how they thought their students might have used graphics calculators in answering the questions. Fourth, two examination markers, both Heads of Mathematics’ Departments and experienced in using the calculators, were interviewed after marking had finished. They were asked about their perceptions of the form and adequacy of students’ solutions. The examination paper was the focus of discussion in all interviews.

3.2. Theoretical perspective

In accordance with the constructivist notion of publicly accepted mathematical knowledge [6], traditional standards determine what are acceptable answers and adequate written working in answering examination questions. However, what is commonly accepted or adequate is open to debate, particularly in the presence of innovations such as allowing the use of technology in public examinations. This paper is part of the debate associated with calculator-assisted answers in the Calculus TEE. A rigorous approach has been adopted here when critiquing the form of students’ examination responses. This does not necessarily reflect how students’ answers were penalized in deficit.

4. Analysis

The analysis centres on the prevalence of the different methods used by students in the eight parts of the six examination questions for which quantitative data were collected. A detailed qualitative analysis describing the processes students followed and the dilemmas they faced in answering 15 part-questions, among eight questions in the nineteen-question paper, where graphics calculators could be used or were used inappropriately, has been reported elsewhere [7].

In the analysis, each question is stated and our view, informed by discussion with teachers and markers, of an acceptable calculator-assisted answer is given. Then, a summary of the numbers of students choosing various traditional and graphics calculator-based methods is provided, together with students’ results for the various methods. The summary for each question is followed by a brief discussion of problematic student answers that were associated with calculator usage.

Data for some scripts in the markers’ sample were incomplete in that markers identified the methods used or recorded the marks awarded for only some questions. These omissions in the recorded data are tabulated in the summaries below and are accounted for by students not answering the question or using methods that were not listed as options on the data recording sheets. Calculator
Let $f(x) = \exp(-x)$. Sketch the graph of the inverse of $f$, $f^{-1}(x)$, clearly indicating all intercepts and asymptotes.

**Solution:** See figure 1.

Results: The data summarized in table 1 indicate whether students first graphed $f(x)$ and then reflected it over $y = x$, or first calculated $f^{-1}(x)$ and then graphed it. In view of the definitions of the given function and its inverse, students most likely used their graphics calculators for graphing in both methods.

Of the 205 students in the sample who graphed the inverse function $f^{-1}(x)$ after calculating it and whose mark was recorded, 105 (51%) scored full marks (see table 1), an indication of competent calculator usage. However, perusal of scripts showed that some students who chose this method sketched a graph with finite range. That is, they failed to recognize the asymptotes at $x = 1$ and $x = 0$. This misconception is an artefact of the screen resolution. The choice of an inappropriate scale (see figure 2) results in a discretization of the $x$-axis which does not enable a student to see the function values close to $x = 1$ or $x = 0$. That is, valuable information about asymptotic behaviour is not displayed. Another problem exhibited in students’ written answers that is attributable to the calculator display (see figure 2) was not showing the curvature of the graph, or showing it incorrectly.

![Figure 1. Graph of $f^{-1}(x)$ for $f(x) = 1/(1 + \exp(-x))$.](image)

<table>
<thead>
<tr>
<th></th>
<th>Reflecting $f(x)$</th>
<th>Calculating $f^{-1}(x)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. students choosing the method</td>
<td>138</td>
<td>227</td>
</tr>
<tr>
<td>No. students whose mark was recorded</td>
<td>123</td>
<td>205</td>
</tr>
<tr>
<td>No. students with full marks</td>
<td>66</td>
<td>105</td>
</tr>
<tr>
<td>Mean mark for those with a recorded mark$^a$</td>
<td>2.8</td>
<td>2.7</td>
</tr>
</tbody>
</table>

$n = 404$ (of which 39 were not recorded as choosing either of the listed methods)

$^a$maximum = 4

Table 1. Method chosen by students for finding the inverse function.
The mean mark of 2.7 out of a possible 4 (see table 1) is explained by these errors, and also by students not deriving a correct equation for $f^{-1}(x)$.

When students adopted the alternative method of reflecting $f(x)$ over $y = x$, errors occurring were associated with reflection, rather than with interpretation of the calculator display of the graph of $f(x)$. Of the students who did not reflect $f(x)$ or calculate $f^{-1}(x)$, (39 of the 404 students in the sample), some provided only a graph of the inverse, which is explained by them graphing $\{ (y, x) : y = f(x) \}$ in the parametric facility on their calculator. Others graphed the reciprocal of $f$ rather than its inverse. This is explained by students associating incorrectly the reciprocal functions INVERSE (on some calculators) and $x^{-1}$ with the operation of finding the inverse of a function.

Question: Find the area of the region bounded by the curves $y = 3 + 2x - x^2$ and $y = -5$.

Solution: The area of the region is given by $\int_{-2}^{4} (3 + 2x - x^2 + 5) \, dx = 36$.

Results: The data summarized in table 2 indicate whether students worked the integral symbolically, or gave only a numeric answer that suggested calculator evaluation.

The integral was relatively easy to evaluate symbolically so that the 163 (40%) out of 404 students in the sample (see table 2) who used their calculators possibly gained no time advantage and the mean marks for the different methods were similar (see table 2).

A number of students split up the region, possibly because co-ordinates of graphs are readily available on graphics calculators. This approach often led to incorrect answers because of a misidentification of the integrals representing the desired part regions. For example, $\int_{-2}^{1} (3 + 2x - x^2 + 5) \, dx$ represents the area of region A (see figure 3) but some students mistakenly evaluated area of region B, and duplicated their error for the integral between $x = 3$ and 4 (see figure 3).
Another error was to write the answer as 35.9999, students not recognizing the need to correct the inaccuracy of their calculator.

Question: Determine the following limits showing your reasoning.

(a) \( \lim_{x \to 1} \exp(x) + 4 \)
(b) \( \lim_{x \to -1} \frac{x^3 + x^2 + 5}{x^3 + 3} \)
(c) \( \lim_{t \to 0} \frac{\tan^2(3t)}{t} \)

Solutions:

(a) \( \lim_{x \to -\infty} \frac{\exp(x) + 4}{2 \exp(x)} = 0.5 \)
(b) \( \lim_{x \to -1} \frac{x^3 + x^2 + 5}{x^3 + 3} = 2.5 \)
(c) \( \lim_{t \to 0} \frac{\tan^2(3t)}{t} = 0 \)

For graphical reasoning to support the answer, see figure 4.

Results: The data summarized in table 3 indicate whether students used graphical or numeric methods that are both potentially graphics calculator based, or traditional symbolic methods.

Only a small number of students (see table 3) chose to provide graphical reasoning for the limits. For those who provided graphs, omissions were not including the asymptote in part (a), failing to identify the point \((-1, 2.5)\) either with its co-ordinates or with the scales on the axes in part (b) and not showing the discontinuity at \(t = 0\) in part (c). The discontinuity is not easily apparent on a calculator-generated graph, leading to the misconception of portraying the function as continuous at the origin. Substitution reasoning was more commonly
adopted (see table 3) than graphing and often students’ answers were displayed in tables similar to those on graphics calculators, suggesting that the technology was used rather than a scientific calculator. Insufficient reasoning was, in (a), providing only two substitutions which are not enough to show a trend; in (b), evaluating the expression at \( x = -1 \) without justification; and in (c) giving only one substitution either side of zero. The mean marks achieved for all limits for graphical and substitution approaches, and the proportions of students having chosen one of these approaches and receiving full marks, were lower than for traditional symbolic approaches (see table 3). However, some of the differences were only marginal and for part (b) we question the large number of students recorded as using symbolic reasoning because perusal of scripts showed few instances of it.

Some students gave an answer of one for the limit in (a). This error is caused by the limitations to storing very large or very small numbers in graphics calculators. For example, for every \( x > 1151.3 \), \( \exp(x) \) exceeds the capacity of the Hewlett Packard HP38G resulting in the graphical and calculation effects illustrated in figure 5.

Question: If \( z = \frac{2 - i}{1 + i} - \frac{6 + 8i}{u + i} \) where \( u \) is a real number, find the values of \( u \) which make the complex number \( z \) lie on the line \( y = x \) in the Argand plane.

Solution:

\[
\frac{2 - i}{1 + i} - \frac{6 + 8i}{u + i} = \frac{1 - 3i}{2} - \frac{6 + 8i}{u + i} \times \frac{u - i}{u - i} = \frac{1 - 3i}{2} - \frac{6u - 6i + 8ui + 8}{u^2 + 1}
\]

Equating real and imaginary parts, we find

\[
\frac{1}{2} - \frac{6u + 8}{u^2 + 1} = -\frac{3}{2} - \frac{8u - 6}{u^2 + 1},
\]

so \( u = -3 \) or \( u = 2 \).

Results: Markers were asked to indicate if students had provided symbolic working for solving the equation that equated real and imaginary parts, or whether a numeric answer was given without the usual amount of supporting working, which suggested solving on a graphics calculator. Table 4 summarizes the results.

For a large number (143) of students in the sample (404) no method was recorded, which is explained by students abandoning the question before completion. However, the mean marks of 1.3 for the graphics calculator approach and 0.9 for a symbolic method, achieved on the question worth 2 marks, suggest there

\[
n = 404 \text{ (of which 21 in (a), 11 in (b), 55 in (c) were not recorded as choosing any of the listed methods)}
\]

\[\text{Table 3. Type of method chosen by students in limits questions (a), (b) and (c).}\]
was benefit in using the calculator, thus avoiding possible errors in symbolic manipulation. Some students persevered with simplifying the fractions past what has been shown in our solution. This unnecessary simplification reduced the time advantage of a graphics calculator approach.

A few students wrote only the answers for this question. A possible method was to graph the real and imaginary parts of the given equation as functions on a graphics calculator, and to read the x-coordinates of the points of intersection for their answers. For example, the prefixes RE and IM on the HP38G can be used to isolate the real and imaginary parts (see figure 6). This direct way of obtaining solutions had not been anticipated in setting the question.

Question: Consider the complex numbers of the form \( z = r\text{cis}\theta \) where \( r = \theta \).

(a) Sketch the locus (set of points) of \( z \) in the Argand plane for \( 0 \leq \theta \leq 2\pi \).
(b) Write \( z \) in Cartesian form in terms of \( \theta \).

If \( z = f(\theta) + ig(\theta) \) where \( f \) and \( g \) are functions with continuous derivatives, then the length \( L \) of the curve which is the locus of \( z \) for \( a \leq \theta \leq b \) is given by the equation

\[
L = \int_{a}^{b} \sqrt{(f'(\theta))^2 + (g'(\theta))^2} \, d\theta
\]

(c) Find an expression for the length of the curve from part (a), simplifying your answer as far as possible.
(d) Calculate the length of the curve from part (a).

Solution:

(a) See figure 7.
(b) \( z = \theta \cos \theta + i\theta \sin \theta \).
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(c) \( L = \int_0^{2\pi} \sqrt{1 + \theta^2} \, d\theta \) which needed to be obtained symbolically.
(d) 21.26 (2dp) which students could only evaluate on a graphics calculator.

Results: The results summarized in table 5 indicate whether students provided a numeric answer, or did not provide a value, for the calculator-evaluated integral in part (d).

The low number of students (see table 5) evaluating the integral in part (d) of the question was not a matter of students not recognizing to use their calculators: they did not get far enough in the question to do so. Perusal of scripts showed that many students failed to make progress with early parts of the question.
Some students drew the graph for part (a) with no working, which is explained by them graphing it as a polar equation or using parametric equations on their calculators. Although these methods are obvious in retrospect, we had not anticipated them. Question: A function is defined by the equation \( f(x) = 1 - x/(x - 1)^2 \). Sketch the graph of \( f(x) \), indicating all asymptotes and the co-ordinates of any turning points. 

Solution: See figure 8.

Results: The data summarized in table 6 are the results for students who chose a symbolic approach to establishing the nature of the graph and for those who appeared to use their graphics calculator by only providing the graph.

The 321 (79%) out of 404 students (see table 6) who appeared to use their graphics calculators by providing the graph without working chose the time efficient option for answering this question. However, the mean mark of 3.7 and that only 66 (23%) out of 289 students providing the graph only (see table 4) scored full marks, indicates students encountered difficulties in interpreting the calculator screen display. Errors were the inclusion of a turning point at \( x = 1 \), possibly found by running the cursor along to the bottom of the graph on the calculator screen; failure to identify the turning point at \( x = -1 \); and for the left branch of the graph to drop below the horizontal asymptote. In fact, close to half the students whose scripts were sighted failed to include the horizontal asymptote. However,
judging by the mean marks (see table 6), students who chose to provide the graph only did not score significantly differently from those who used symbolic working.

5. Discussion

5.1. Errors and difficulties

Interviews with students as to how they used their calculators were a vital part of explaining the source of students’ errors because calculator processes are not always apparent from examination scripts. One student reminded us of the misuse of the INVERSE function, which perpetuates the error of plotting the reciprocal function \( y = (f(x))^{-1} \) when the inverse function \( y = f^{-1}(x) \) is required. Another gave a rich description of the difficulties encountered while attempting to interpret the screen display of a graph [7].

The analysis of candidates’ examination answers indicates that interpretation and transcription of graphs are major areas of difficulty for many students. The following types of errors were observed:

(a) asymptotic behaviour was not recognized: a function stopped on vertical asymptotes instead of approaching them;
(b) a point discontinuity was not located;
(c) the limiting value of a function was believed to be correct even though the capacity of the calculator to store large numbers had been exceeded;
(d) horizontal asymptotes were omitted, and a function drawn to drop below its limiting value;
(e) a non-existent turning point was located on an asymptote; and
(f) a turning point was not located even when the question suggested one existed.

Boers and Jones [1] observed students having similar difficulties with point discontinuities and asymptotes and Tobin [8] discusses students’ difficulties in copying calculator-generated graphs, as we noted.

Other errors included incorrectly subdividing the integral associated with finding an area between two curves, and not rounding answers that were generated inaccurately on the calculator. In addition, students failed to provide a sufficiently detailed table of values to support calculator-assisted numeric evaluation of limits, and to adequately label graphs when using them as reasoning for evaluating limits.

5.2. Choosing between technology-assisted and traditional methods

The outcomes for the last question discussed above indicate that a significant number of students (21%, \( n = 404 \)) did not use their calculator for graphing even when there was a time advantage to do so. Also, as Boers and Jones [1] found in a university calculus examination with use of graphics calculators, the vast majority of students chose traditional methods for limits rather than a calculator-based approach. These apparent underutilizations of the technology as the first option for solving problems by some students, do not preclude the possibility that students used their calculators for checking. The six students interviewed had all checked at least some answers [7], but there is no evidence that this checking was widespread: the correction of initially incorrect answers was not noted in the perusal of scripts.

Underutilization of the technology might have arisen because students were not sure that a calculator method would yield the answer. For example, one student
interviewed thought that \( \lim_{t \to 0} \frac{\tan^2 3t}{t} \) could not be determined graphically. Tabular reasoning might also be viewed as not satisfying the rigour of calculus, which was reflected in one of the interviewed markers’ comments: ‘What knowledge or skill is there in that?’ Justification for graphical and numeric reasoning being adequate in the context of the Calculus TEE is that the syllabus [9] for it states: ‘It is not intended that \( \varepsilon - \delta \) techniques be part of this subject. Limits are still to be defined in an intuitive manner and illustrated wherever appropriate with graphs and numerical calculations’. Misinterpreting ‘show reasoning’ to mean ‘show algebraic reasoning’, for example in the question on limits, was another reason for students not using their calculators when it was possible to do so. The reverse problem in questions not discussed here was of students providing graphical or numeric reasoning when an analytical approach was specified.

In contrast to some students not taking full advantage of the technology, the perusal of scripts indicated that others had used their calculators in ways we had not anticipated. In summary, these were to use the parametric graphing facility to plot an inverse function, to solve a complex number equation, and to plot a vector equation. The very low incidence of these approaches indicates they were not well known and that the students who used the methods had insight, or perhaps the benefit of practice in class with an insightful teacher. Students’ learning to use the technology was only one aspect of allowing graphics calculators for the TEE: a wide range of professional development activities and teachers networking to help each other accompanied the innovation. However, anecdotal comments that the examination gave students little opportunity to use their calculators suggested low appreciation by some teachers of where and how the technology could be used. Apart from the questions described here, graphics calculators were potentially of advantage, over and above a scientific calculator, in several other questions in the examination paper. These included graphing an absolute value function, and obtaining the conditions for continuity and differentiability at points on it; ascertaining visually the roots to which the Newton–Rhapson method would converge for a given equation; evaluating an integral yielding volume, and the solution of an exponential equation [7].

Another aspect in choosing a graphics calculator assisted approach is that it might be quicker than a traditional approach. Students have to judge if the time used to enter equations into the calculator will be well spent. That there was any time advantage for the simple integral evaluating area is debatable, which is reflected in 57% \((n = 404)\) of students choosing a symbolic approach.

The results reported here suggest that choosing to use graphics calculators was not associated, in general, with higher (or lower) marks than traditional alternatives. The value of graphics calculators might therefore primarily lie in the development of student understanding in the teaching/learning process rather than in their use as a tool to maximize assessment scores.

6. Comparative analysis

The introduction of graphics calculators has changed the nature of Calculus examinations to some extent. For instance, allocating ten marks for the question in the 1996 Calculus TEE, which asked students to find the local and global extrema for \( f(x) = 2 + |x^2 - 7x + 12| \), may no longer be appropriate, and students would be expected to use their calculators rather than an analytical method. Changes can be
discriminatory in their effect. To explore the possibility that the introduction of graphics calculators might have changed the distribution of scores for boys and girls, we compared the results for the Calculus TEE through the years 1995 to 1998. The percentile plots (see figure 9) of males versus females for the population show similar distributions of results for males and females for each year from 1995 to 1998.

In all instances, the raw examination results of females are higher than those of males at the bottom end while those of the males are slightly higher at the top end. The upper and lower quartiles (see table 7) demonstrate this result.

For 1996–1998, the mean marks out of 180 for female students were slightly higher than those of the male students (0.8 marks higher in 1996, 0.8 in 1997 and 0.5 in 1998), but they were slightly lower in 1995 (0.5 marks). However these differences in means are not statistically significant. No trends are claimed from only one year of experience of allowing graphics calculators in the examination, but the indication from this analysis is that, so far, the introduction of calculators does not appear to be discriminatory with respect to the distribution of raw scores of males and females.
To inquire further if there were any apparent differences in boys and girls performance, we compared the results for the 1998 graphing question described above involving horizontal and vertical asymptotes with results for graphing questions in the 1996 and 1997 papers that were similar. The basis for choosing this type of question for comparison was that in 1998 the answers of a relatively high number of students (79%, \(n = 404\)) seemed to be calculator assisted. A limitation to the comparison is that these were composite questions, involving graphing as a major component but including other parts. For example the 1998 question allocated five marks for graphing and three marks for an application involving the Newton–Rhaphson method. There was no similar question in the 1995 paper. Analysis of the distribution of marks for females and males for these questions showed they were very similar, with the medians, upper quartiles and lower quartiles being identical for females and males within years, except that the lower quartile was slightly lower for boys than for girls in 1997. The close similarity in the distributions and the closeness of the mean marks between girls and boys for each year (table 8), again suggest that there is no strong indication that the introduction of calculators has been discriminatory in their effect, except the reversal in 1998 to boys mean performance on the questions being marginally higher than that of girls is noted. Further comparisons between years (say of average percentage marks) for these questions are not appropriate because the interpretative parts of the questions differed.

The 1998 question involving the graph of an inverse function, which attracted high calculator usage, shows again an almost identical distribution of the marks for boys and girls and a slightly higher mean for males than for females (4.99 versus 4.97 out of 9). There were no comparable questions to it in previous papers for which data were available. The results again suggest that the introduction of the calculators has been non-discriminatory.

The analysis also highlighted that the number of candidates for the Calculus TEE has been decreasing over recent years. This decline is more pronounced in
numbers for female than for male students in both absolute and percentage terms. The number of female candidates dropped by 20% from 1995 to 1998 (706 in 1995, 660 in 1996, 618 in 1997, 562 in 1998) while the corresponding drop for males is only 5% (1387 in 1995, 1264 in 1996, 1270 in 1997, 1320 in 1998). This significant decline in the numbers of female students has occurred at the same time as the use of technology in the curriculum has increased, so the question must be asked if the two changes are related.

7. Conclusion

The first Calculus TEE where graphics calculators have been allowed has highlighted problem areas deriving from use of the technology. Of these the foremost are the interpretation of graphical information and an apparent under-utilization by students of the calculators. In this first examination with the technology, underutilization is explained by uncertainty as to when use of graphics calculators is appropriate, which may cease to be a problem as calculator familiarity increases. Problems with the interpretation of graphical information indicate that instructional time needs to be spent on exploring the limitations of the calculators. First indications are that no significant differences between girls’ and boys’ examination performances are attributable to the use of graphics calculators.

Issues of assessment are the related questions of what skill in using the calculators can be assumed, and what marks to allocate questions which require extended symbolic working but which are quickly solved on the calculator. For the US AP Calculus, examinations are based on the assumptions that students can: 1. produce the graph of a function within an arbitrary viewing window, 2. find the zeros of a function, 3. compute the derivative of a function numerically, 4. compute definite integrals numerically’ [3]. While the West Australian approach is non-prescriptive, the skills that were assumed, and used, fell within the AP Calculus statement, and the marking scheme generally reflected those assumptions. There was an anomaly in 12 marks out of the total 180 being allocated to solving the complex number equation: the calculator method used by a few students was not anticipated. The outcomes from the 1998 Calculus TEE will inform the setting of future papers, with the view that the examination is to test calculus and not sophisticated uses of the technology.

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References

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