The Year 2000 Calculus Tertiary Entrance Examination in Western Australia: Roles for a Graphics Calculator and Achievement by Gender

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Abstract

In this paper we report results of our study of gender-related effects and the use of graphics calculators in the year 2000 Western Australian Calculus Tertiary Entrance Examination (TEE). Background to our inquiry is that mean total scores on the examination for 1995-2000, three years prior to and three years after the inclusion of graphics calculators on it, show that since 1996 girls' mean performance has been superior to that of boys. At the same time, participation in TEE Calculus has declined by nearly ten percent from 1995 to 2000, with most of the decline attributable to fewer females choosing to study the subject. Our in-depth study of the questions from the 2000 examination shows that in most individual questions where girls do better than boys the role for technology is limited and the skills called upon for successful solution are largely analytic. We illustrate our findings with data for two questions that highlight differences in performance between students of each gender on analytic parts and parts involving calculator graphing, and routine and non-routine graphical interpretation. We also categorise and link to performance by gender the different roles that graphics calculators could have played across all questions in the examination, for example, for checking, for computation, or for providing a graph to allow an integrated visual-algebraic approach to problem solving.

Introduction

Literature and current thinking on gender-related differences in mathematics are reviewed in a set of articles in a recent issue of the Educational Researcher (e.g., Fenema & Carpenter, 1998). Research points to females as a group learning mathematics less adequately than males, but that gender differences may be diminishing. Other evidence indicates that achievement in mathematics is similar except at the most advanced levels. Males' performance is found to be superior to that of females on complex tasks, and males use invented strategies (in contrast to standard algorithms) more frequently than females which may be an unwitting perpetuation by teachers and students of the stereotypes that 'girls are compliant and seek reliable ways to an answer' and 'boys are more independent and have the confidence to take risks in their mathematics'.

In relation to the use of graphics calculators, relatively little attention has been given in the literature to the effects of gender. However, there is widespread evidence that both boys and girls benefit from their introduction as measured by superior performance by groups using the calculators compared to groups taught without the technology (e.g., Nimmons, 1997; Ruthven, 1990; Smith & Shotsberger, 1997). Differences in effect have also been recorded, in a variety of settings:

1. Girls seemed to benefit more than boys from the availability of graphical checks on items requiring formulae for given graphs (Ruthven, 1990). However, there were no gender-related effects on test items that involved *interpretation* of verbally contextualised graphs.
2. Upon introduction of the technology both males and females improved on visual items, but girls showed greater gains than boys (Dunham, cited in Boers & Jones, 1993, Nimmons, 1997).
3. Females' examination success (over that of males), when calculators were allowed, was attributable to their superior achievement in algebraic questions (Boers & Jones, 1993). A suggested explanation was that with the introduction of the calculators, males were more interested in the tool and no longer as keen to study and exercise manipulative skills.
4. Males chose a calculator option more often than pure algebraic, or mixed 'algebraic and calculator' approaches where questions required graphing, (Boers & Jones, 1993; Smith & Shotsberger, 1997) while a greater percentage of females chose an algebraic method. On an item requiring the integration of algebraic answers (from early parts of a question) into the drawing of a graph, the percentage of males who were successful in integrating the information was greater than the percentage of females.
5. Where there was a choice of method, high confidence females were more likely to use an algebraic approach, high confidence boys were most likely to mix the methods, and low-confidence females and males relied on the calculator more than on algebraic approaches (Dunham, 1991). Boers and Jones (1992) also observed lower achieving students to rely more on the calculator than other students.

These findings informed our inquiry into discernable gender-related effects in the year 2000 Calculus Tertiary Entrance Examination (TEE) so that variables which we consider in our analysis are the complexity, mean marks and roles of a graphics calculator for all questions, and microanalyses of the demands of and performance on all parts of two questions.

Research Method

The Curriculum Council of Western Australia which administers the TEE supplied us with the marks for each candidate for each examination question and with summary statistics, for the years 1995-2000. The question by question mean results for the 2000 Calculus examination were based on students who attempted the questions. Two-sample *t*-tests were carried out on the results for the cohort to test the statistical significance of the differences in mean scores of boys and girls.

We draw on results of our previous study (Forster & Mueller, 2001) to explain the differences. In it we classified examination questions for 1996-1999 according to six categories including:

- the role of a diagram in the solution (whether students were asked to interpret a diagram, make one, or a diagram could have assisted the solution) and
- the role of graphics calculators (questions were calculator active, where there was a definite advantage in using them, neutral, where calculator and analytic methods were both viable, or calculator inactive).

For the current study we each classified the year 2000 examination questions according to these categories. We each did the classification separately and negotiated our differences in opinion to reach agreement. When we refer to use of a graphics calculator in the analysis we are referring to use of capabilities over and above those of a scientific calculator.

Another source of data was the second author recorded the nature of students' answers and part marks awarded on the 214 scripts (6 bundles) that she marked. Scripts from a school are allocated among several bundles, bundles are allocated randomly to markers. Each script is marked by two markers, and differences reconciled.

Background

The Year 12 TEE Calculus course is a specialist mathematics course that attracts approximately 2000 students throughout the state each year (compared to 6000 for Discrete Mathematics and 5000 for Applicable Mathematics). Calculators without a computer algebra facility and the Hewlett Packard HP38G with limited symbolic capabilities are approved for TEE purposes. Persisting trends in the Calculus are that half as many girls as boys sit the examination and participation by girls is declining (see Table 1). Since 1996, the mean total score for girls has consistently exceeded the mean total score for boys. The difference in scores closed slightly in 1998 upon the introduction of graphics calculators, but a simple causal effect is not assumed. Other variables are relevant to that outcome, including that students found the 1998 paper relatively 'hard' as indicated by the mean scores on it. Subsequently the gap has widened so that, in 2000, for the first time in the six year period, a statistically significant difference in mean scores occurred (at the 98% confidence level).

Table 1: Examination results for the population on the 1995-2000 questions on the total raw scores

	1995	1996	1997	1998	1999	2000
[a] Girls' mean mark	103.45	104.97	120.29	99.01	106.08	102.37
Number of girls	706	660	618	562	577	549
[a] Boys' mean mark	104.04	104.19	119.49	98.55	104.62	97.82
Number of boys	1387	1264	1269	1320	1358	1337

[a] Maximum mark = 180

The drop in the numbers of females coincided with an increase in the use of technology for the teaching/learning of mathematics. Other factors relevant to the decreases are changes of university entry requirements leading to Year 12 Calculus no longer being a prerequisite in most courses, with universities opting to offer bridging courses for Calculus instead. A further factor, from 1999, is a change of the university entry requirement from six subjects with satisfactory performance to four.

Results in the 2000 Calculus TEE

Mean scores by gender for each of the 20 questions in the 2000 Calculus TEE are summarised in Table 2. We also list our categorisations for the opportunities for graphics calculator usage and the role diagram played in each question.

The results show that significant differences favoured girls on ten questions. Seven were technology inactive: 1, 5, 6, 7, 8, 11 and 16. Question 1 required the identification of regions in the complex plane and called on visual perception and translation of graphs to symbolic form. Translation between representations is usually considered to raise the level of a question above being simply skills-based (Senk, Beckmann & Thompson, 1997); but the relationships in the question were ones that are commonly drilled as part of the Calculus course. Questions 5-8 concerned rules of differentiation, integration, the equation of a tangent to a curve and continuity and differentiability of a function at a given point. They called on standard algorithms, and that girls performed better on them is consistent with Boers and Jones (1993) findings. Taken together, Questions 1 and 5-8 were found to be amongst the easiest questions on the paper by the cohort (see Table 3), as indicated by the mean percentage scores for each question.

Table 2. Mean scores on questions from the 2000 Calculus TEE and question characteristics

Question	1	2	3	4	5
Girls' mean score	4.22**	3.46	2.23	3.29**	5.25**
Boys' mean score	4.06	3.34	2.29	2.93	5.04
Graphics calculator	[a]I, I	N, I, I	I	N, I	I, I
Role of diagram	[b]I, I	N, A, A	N	N, N	N, N
Question	6	7	8	9	10
Girls' mean score	8.18**	5.77**	5.45*	4.51	5.06
Boys' mean score	7.40	5.37	5.30	4.32	5.14
Graphics calculator	I, I, I	I	I, I	I, I, I	A, I, N
Role of diagram	N, N, N	N	N, N	N, N, N	M, I, A
Question	11	12	13	14	15
Girls' mean score	3.33*	4.87	8.75*	3.37	3.83
Boys' mean score	2.96	5.14*	8.33	3.21	3.87
Graphics calculator	I	I, I	N, N, I, I, A, N	N	I, N
Role of diagram	I	I, I	N, A, N, N, M, A	A	N, M
Question	16	17	18	19	20
Girls' mean score	6.88*	6.62	6.05	6.91	6.37**
Boys' mean score	6.28	6.79	6.67**	7.12	5.46
Graphics calculator	I, I, I, I	I, I, N, A	A, A, A, N	I, I, N, N	I, I, N
Role of diagram	N, N, N, A	N, N, A, M	A, A, A, A	I, N, N, I	N, N, A

[a] I = inactive, N= neutral, A = active. I, I refers to I for part (a) of a question and I for part (b) of a question.
[b] N = none or superfluous, A = assist, M = make, I = interpret. Here I, I refers to interpret for question-parts (a) and (b).
* significant at the 95% confidence level, ** significant at the 99% confidence level

Table 3. Questions ranked according to mean score for the cohort, and group with significantly superior performance indicated.

Question	8	5	1	7	3	2	6	4	13	18
Mean %	89	85	82	78	76	68	64	61	61	59
Superior group	F	F	F	F			F	F	F	M
Question	19	10	12	9	17	16	15	14	11	20
Mean %	59	57	56	55	48	46	43	41	38	38
Superior group			M			F			F	F

In contrast, for Questions 11 and 16 where girls' achieved significantly better results, candidates generally scored very poorly. Question 11 was on related rates. It required students to interpret a diagram in order to set up a function, but called in large part on analytic approaches. In Question 16 students needed to construct a formal proof that involved the solution of simultaneous equations arising from properties of complex numbers. One of the equations was a quadratic.

The remaining three questions for which the mean scores for girls were significantly better than those for boys were Questions 4, 13 and 20 and *graphics calculator* use could have played a role in answering them. Question 4 required the determination of the limits: (a) $\lim_{x\to\infty} [(x^2/(x+3)^3]$ and (b) $\lim_{h\to 0} [(\sqrt{a+h}-\sqrt{a})/h]$, $a > 0$; Question 13 was on exponential growth and decay and will be discussed in the next section; and Question 20 concerned volume and surface area, and is given below as stated in the examination paper, except for spacing (Curriculum Council, 2000a).

A sphere is obtained by rotating about the *x* axis a semicircle whose equation is $y=\sqrt{r^2-x^2}$ and is sliced vertically at $x=a$ and $x=b$, where $-r \le a < b \le r$.

(a) Write down the integral for the volume of the slice.

(b) Find the area A of the curved surface of the slice, given that $A=\int_a^b 2\pi\, y\sqrt{1+(dy/dx)^2}\;\; dx$. Simplify your answer.

A spherical rock melon has a diameter of 22cm. Arthur takes a 2cm slice off the end of the melon and Martha takes the next slice, also 2cm thick.

(c) Show that Martha's slice has more than twice the volume of Arthur's slice, but the same curved surface area.

Question 4 called on standard algorithms. Students could check their answer to (a) graphically or using the table of values on their calculator, and it is relevant that checking on the calculator is potentially of more benefit to girls than boys (Ruthven, 1990; Smith & Shotsberger, 1997). Alternatively, from the start, students could have used a visual or numeric approach on their calculator for the limit in (a). These methods fit within the intentions of the Calculus course (Curriculum Council, 2000b).

Students were guided through Question 20 via a number of parts: Question 20a, which involved setting up an integral for volume, was routine. Question 20b required relatively complex algebraic manipulation. In (c), students needed to extract the mathematics from the melon context, and most likely would have used a diagram--generated without the calculator in view of the standard form of the function. Then, students needed to set up the definite integrals and evaluate them. They could be evaluated or checked on the calculator. An advantage also of calculator evaluation was that students who were not successful with part (b) could still work with the unsimplified integral on the technology. Overall this question was found by students to be one of the most difficult on the paper as indicated by the mean score on it (see Table 3), but it is relevant that it was the last question of the paper and students may have been short of time.

There were two questions (12 and 18) on the paper on which significant differences favoured boys. Question 12 required the identification of the features of the graph of a function, and construction of the graph of its second derivative from the graphs of the function and its first derivative. It is discussed in the next section. Question 18 was on rectilinear motion. Three parts were *calculator active* and the last part was *calculator neutral*. It read (Curriculum Council, 2000a):

A hot air balloon begins a 60 minute flight by rising upwards from the side of a hill. Its vertical velocity *v* (metres per minute) is given by $v=t(t-35)(t-60)/1400$ where *t* is the time from the start in minutes.

(a) What is the maximum upward velocity?

(b) While the balloon is ascending, when is its acceleration the greatest?

(c) When does the balloon reach its maximum altitude and how far above its starting point is it at that time?

(d) Does the balloon land above or below its original elevation? Explain your reasoning.

The graphics calculator could be used, first, for the automated evaluation of the maximum turning point on the velocity graph in part (a). For part (b), a calculator-generated graph of acceleration, the derivative of the given function, could have been used to find the maximum acceleration and allowed identification of it as a global (rather than a local) extremum. Part (c) could be answered by the evaluation of an appropriately chosen integral. This required the combination of graphical information, namely the location of the zeroes of the velocity function, the notion that positive velocity corresponded to a rising balloon, and the interpretation of the integral over the velocity as the total displacement. Part (d) could have been solved by inspection of the velocity graph alone or by calculation of the definite integral over the entire time period. The integrations in (c) and (d) could have been passed to the calculator.

Apart from the twelve questions discussed above, there were eight other questions on the paper. In three of these, differences in performance marginally favoured girls. These were:

- Question 2, which required a proof that, $f(x) = (x+2)/(x-1)$, is its own inverse, and to provide a property of the graph of *f* that is a consequence of it. Students also had to write down another function that is identical to its inverse. The calculator could have been used to check (a) and (c) and having the graph available could have assisted solution of (b).
- Question 9 was on the approximation principle and called solely on analytic approaches.
- Question 14 asked for the exact solutions to a complex quartic equation. The calculator could be used for checking, or for calculation if students knew the conversions from decimal to exact values, but the conversions were not ones that are common.

Questions on which mean scores were marginally higher for boys were:

- Question 3, which involved computing a composite function and stating its domain and range.
- Question 10 asked students to graph two functions (given in factorised form) and then calculate a maximum area related to them. It was a relatively challenging question (see Table 3) and required visual discernment to formulate the area required.
- Question 15 involved a complex number calculation and asked for the graph of the relationship obtained ($|xyi| \le 2$).
- Question 17 had a skater travelling on an ellipsoidal path**.** The question asked for the period of the motion, expressions for velocity and speed, positions of maximum speed, and a graph of the motion with positions and velocity at specified times. Students could have used their graphics calculators to check the period--by plotting the displacement function in the parametric graphing facility, with the range for time set to the period. Point identification facilities linked to the graph could be used for positions at the required as could the table of values.
- Question 19 was on simple harmonic motion. Two parts called for interpretation of a diagram. The calculator could be used to obtain or check time for maximum velocity.

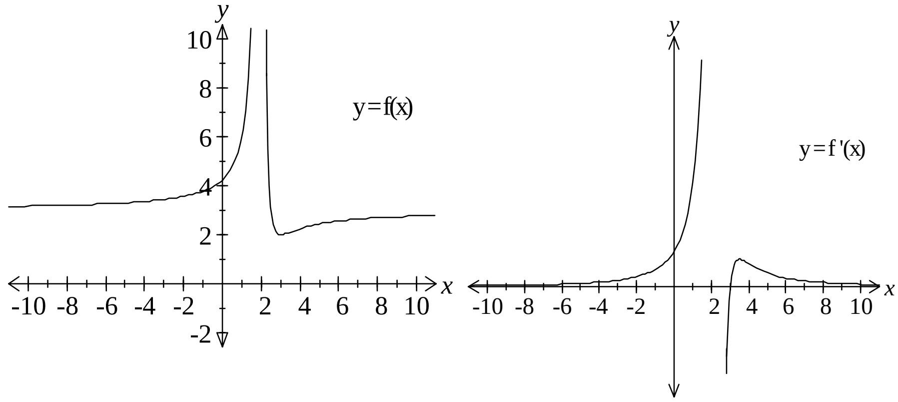
Boys and Girls, Interpretation and Visualisation

In this section we consider in detail Questions 12 and 13 and quote them below from the examination paper (Curriculum Council, 2000a). Question 12 is technology-inactive and calls upon the interpretation of two graphs that were provided. Question 13 is in part *calculator-active* and requires the generation of a graph. In Question 12 boys performed significantly better than girls while the reverse is the case for Question 13 (see Table 2). We chose the two questions for detailed inquiry because of their nature, and prior to the statistical analysis.

Question 12: The graphs of a function $f(x)$ and its derivative $f'(x)$ are shown below:

(a) For $f(x)$, mark any turning points and points of inflection, and draw in any asymptotes suggested by the graph. Clearly identify the relevant equations or co-ordinates, estimating where necessary.

(b) Sketch the graph of $f''(x)$ on the same axes as the graph of $f'(x)$.



Question 13: The size of $P(t)$ of a population of bacteria in a culture at time t minutes is modeled by the equation $dP/dt = P - P^2/1000$ …………....(1)

For which values of P is the growth rate dP/dt zero?

(a) For which value of P is the growth rate greatest?

(b) Show by differentiating that $P = 1000/(1 + Ce^{-t})$ satisfies equation (1), for any value of the constant C.

(c) Find C, given that at time $t = 0$ the size of the population is 100.

(d) Sketch a graph of P as a function of t.

(e) What is the limiting size of the population as $t \to \infty$?

Question 12 called on sound understanding of the relationship between the graph of a function and its derivative. The formula of the original function was not provided, so a calculator could not be used to check the answers. Part (a) of the question required the identification of key properties of the graph of the function using the graph of the derivative as an aid. This part of the question was the more routine one because questions in the 1998 and 1999 TEE asked for functions to be graphed and asymptotes and turning points identified--where calculator graphing was widespread (Forster & Mueller, 2001). With 12a, in the sample of 214 scripts marked by the second author, there was no substantial difference in mean performance between boys and girls (mean: 2.63 for boys versus 2.57 out of 5 for girls). Part (b) of the question required students to infer the graph of second derivative from the graph of the first derivative. The rates (for the sample) for correct identification of the component parts are summarised in Table 4.

Table 4: Sample data on % of correct components by gender for part (b) of question 12.

	Correct left branch	Correct x intercept	Correct asymptotic behaviour towards ∞	Correct asymptotic behaviour towards 2
[a] Girls	66	68	41	61
[a] Boys	76	75	65	76

[a] Number in the sample girls = 57, boys = 157; number who attempted (b) girls = 44, boys = 139;

The mean mark of boys for 12b was significantly better than that of girls (2.94 for boys, 2.45 for girls out of 4 with a p-value of 0.045). We need to note that for this sample the mean performance of girls overall was inferior to that of boys (96.3 for girls versus 101.7 for boys), but the differences between the sample and population means (see Table 2) are not statistically significant.

Overall on Question 12 the population of boys scored significantly better than girls (Table 2). Further, the distribution of marks by gender for the population (see Figure 1a) indicates boys performance was superior at all but the lowest levels of achievement. For the sample, the differences in performance were significant and more substantial for part (b) than for part (a), and boys' performance was superior in all aspects of part (b). Part (b) called for high levels of visual discernment and non-routine interpretation. These results are consistent with the findings that differences favour boys on more complex tasks (Seegers & Boekaerts, cited in Fenema & Carpenter, 1998), with the caveat here that the tasks involved visual reasoning. The outcomes are also relevant to the issue of whether use of graphic calculators is differential in the effect on the development of visual reasoning, where this has been noted to have no effect (Cassity, 1997) or to favour girls (Dunham, 1991; Nimmons, 1997), with girls starting at a lower level (Dunham, 1991).

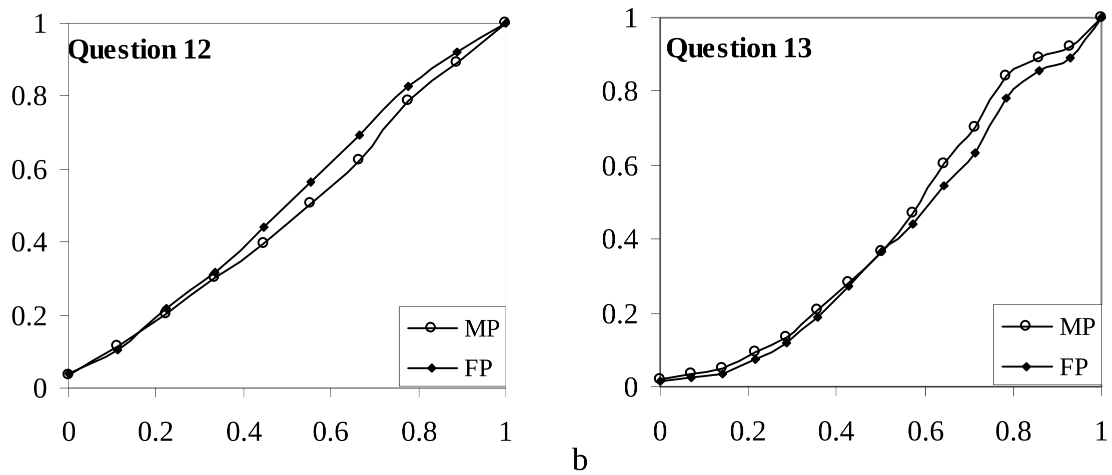


Figure 1: Cumulative distribution of percentage marks for males (MP) and females (FP) for the population on Questions 12 and 13

With Question 13, it was asked to test understanding of continuous growth. Part (a), worth 1 mark, was solved easily by factorisation, and could have been solved graphically, but less efficiently, on the calculator. Part (b), worth 2 marks, was easily solved using differentiation and then solving the equation by hand to obtain the maximum. Part (c), worth 5 marks, was a high-level question and required an algebraic approach. Part (d), worth 2 marks, required relatively simple algebra. Thus, the aggregated marks for parts a-d were associated in large part with algebraic competence, and the differences in girls' and boys' scores (for all students who answered the question) were statistically significant and favoured girls (see Table 5).

On the other hand, part (e) involved the generation of a graph. The given function is not typically taught as part of the Calculus TEE, forcing calculator generation of it. The graphing process involved predicting the limit to infinity to obtain the range for an adequate screen display, thus required integration of algebraic methods to obtain the graph. Then, in drawing the graph students needed to draw in the horizontal asymptote or otherwise ensure their graph did not drift above $f(x) = 1000$. The graph did not require interpretation, except for part (f), but the limit required there would ideally have been obtained before the graph was produced.

Table 5: Performance by gender for the cohort on question 13.

	Question 13a-d		Question 13e		Question 13f	
	[a]Number students	[b]Average mark	Number students	[b]Average mark	Number students	[b]Average mark
Girls	459	6.29**	492	1.91	497	0.83*
Boys	1329	5.94**	1133	1.98	1152	0.87*

[a] number in the cohort girls = 549, boys = 1337, [b]13a-d maximum 10, 13e maximum 3, 13f maximum 1,
* 95% confidence level, ** 99% confidence level

Boys achieved marginally better results on the graph for part (e), and statistically significant (but insubstantially) better results on the limit (see Table 5). Thus, for this question overall there is a repetition of the outcome of girls being stronger with analytic methods and graphing favouring the boys. In view of analytic methods attracting greater marks (see Table 5), the percentage cumulative distribution for the scores in Question 13 emphasizes girls' superiority with analytic methods.

In the sample of 214 scripts, in all cases students' showed little if any working relating to the graph, indicating that a graphics calculator had been used. Data for the sample are summarised in Table 6. They underline that girls had more problems in constructing all aspects of the graph and in establishing the limit. About one third of girls and boys who identified the limit did not obtain an adequate range, indicating that they failed to make the connection between the two quantities.

Table 6: Sample data on % of students who answered 13e and 13f correctly when attempting them

	Adequate range (e)	Correct y intercept (e)	Correct shape (e)	Correct limit (f)
[a] Girls	45	53	51	75
[a] Boys	62	67	65	91

[a] Number in the sample girls = 57, boys = 157; number who attempted (e) girls = 47, boys = 128; number who attempted (f) girls = 48, boys = 131.

Conclusion

On questions where there were significant differences in performance between boys and girls, we have seen girls do better on questions that require solely algebraic methods (Questions 5-8) and where the majority of marks was associated with analytic reasoning (Question 11, 13, 16, 20). Moreover, the questions on which girls achieved the better scores were often the easier questions in the examination paper (Questions 5-8); but included harder questions requiring algebraic methods (Questions 11, 16, 20); and on Question 13, on the part that required a graph, girls' performance was inferior to boys. Successful graphing required students to predict features from a given equation and integrate these into the graphing process on the calculator, which girls achieved less adequately than boys. Where girls scored significantly better on questions that required visual reasoning (Question 1), or could have relied on it (Question 4), these were routine questions.

In spite of differences on the examination favouring girls overall, differences favoured boys marginally better where graphs were required and interpretation was needed (Question 10 and 17); and where a graph could be used to check for maximum velocity (Question 19).

The outcomes of our inquiry reflect previous research findings, but an important aspect is the large population with which we were dealing. Implications for teaching, in the context of preparing students for public examinations like the Western Australian Calculus TEE, are that teachers need to be aware that boys might require encouragement towards using analytic methods alongside graphical methods, and for girls, visual problem-solving skills might need to be highlighted. Moreover, the value placed in public examinations on the different problem-solving approaches could affect students' scores, and so might differentially affect entry to university courses where entry is competitive. However, because Calculus requires a stronger mathematics background than other TEE mathematics subjects and because more than twice as many boys as girls attempt it, we are cautious about making any wider generalisations.

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