Applicable Mathematics Examination Questions: The Impact of Graphics Calculators

U. A. Mueller and P. A. Forster
Edith Cowan University
u.mueller@ecu.edu.au, p.forster@ecu.edu.au

Abstract

Graphics calculators were first allowed in Western Australian Tertiary Entrance Examinations for mathematics and science subjects in 1998. In this paper, we report part of an inquiry into the impact of the introduction of the technology on examination questions in Applicable Mathematics. We provide an overview of the changes in questions overall, then, focus on questions on linear programming and systems of linear equations. We detail changes in the formulation, graphing and calculation required in questions on linear programming, and changes in the methods for solving systems of linear equations.

Introduction

The use of graphics calculators is now widely accepted in upper-secondary mathematics courses. Higher-level computer algebra system (CAS) calculators are also being increasingly taken up, particularly in Calculus, and several major research studies have documented the implementation of both technologies for teaching and learning (e.g., Kendal & Stacey, 2001). Assessment has also been investigated, particularly in Calculus (e.g., Monaghan, 2000). However, there seem to be few studies of assessment in upper-secondary general mathematics subjects. This paper addresses that domain. We report selected findings of our study of examination questions in the Western Australian Tertiary Examination (TEE) in Applicable Mathematics for six years prior to the introduction of graphics calculators (1992-1997) and six years since the introduction (1998-2003). Our interest was in the changes in the mathematical processing and understanding that were being examined, which could be linked to the availability of the technology.

Applicable Mathematics is a Year 12 subject. Approximately 5000 students enrol in it each year and about 2000 of them study Calculus as well. Another 7500 students enrol in Discrete Mathematics, which is the least mathematically demanding subject. Students who choose Applicable Mathematics have usually completed an Introductory Calculus course in Year 11. The syllabus for Applicable Mathematics (Curriculum Council, 2002a) is divided into five topics: Systems of linear equations and matrices; Graphs and solutions of equations; Descriptive statistics; Sets, counting and probability; and Random variables and their distributions. We discuss examination questions on systems of equations (from the first topic) and on linear programming (from the second topic), and provide a less detailed account of changes in other areas.

Non-symbolic graphics calculators and the graphics calculators with limited symbolic capabilities were mandated for the Applicable Mathematics TEE in 1998. Minimum capabilities were specified, including matrix arithmetic, the evaluation of derivatives and definite integrals. Scientific calculators have been allowed for the entire period of our study. The syllabus states that: "students should select and use technologies appropriately" (Curriculum Council, 2002a, p. 47) and "appreciate the benefits of using technology in mathematics" (p. 47). Examiners attempt to minimise advantage/ disadvantage due to differing capabilities of the calculators over and above the minimum capabilities (Curriculum Council, 1998c, 1999c). Programs are freely available on the web that compensate for shortfalls in the various brands of calculator (e.g., Ref1, Ref2).

Examination questions are set also to minimise any advantage of these, as some students may not know about them (Bradley, 1999). There were several minor changes to the syllabus when the calculators were introduced, and there have been others since. Syllabus changes that are relevant to this paper are quoted in the analysis section. Another aspect that is relevant to our findings is the use of 'write-on' examination papers since 1996.

The Literature

Bradley's (1999) analysis of the 1998 Applicable Mathematics TEE, from her viewpoint as examiner and marker, directly relates to our inquiry. She pointed to intentional strategies in setting the examination, namely: opportunities for full utilisation of basic facilities on the calculators (handling matrices etc); increased calls for explanation; and questions where it was possible but inefficient to use the calculators. The last strategy addressed the syllabus objective that students should use technology appropriately. She gave an account of errors and commented on poor performance with explanation. Her final conclusions were that "many students used the calculators when it would have been more efficient to use pen and paper . . . [and] lines of algebra indicated students had not used their calculators when expected to do so" (p. 63).

Our previous study of school-based assessment in Applicable Mathematics (e.g., Forster, Mueller, Haimes, & Malone, 2003) also informed our analysis here. We measured the extent of graphics calculator use in tests, examinations and extended (investigative) tasks, in eight schools over one year. The percentage of marks allocated in tests and examinations to items for which we regarded graphics calculator use to be essential or advantageous over scientific calculator use averaged 17% of total marks allocated, and ranged from 5% to 20% for the eight schools. The topics that allowed greatest use were: Systems of linear equations and matrices, Graphs and solutions of equations, and Random variables and their distributions. Calculator generated graphs were widely used and their availability allowed new styles of question. Twenty-one out of 28 of the extended tasks that we collected allowed graphics calculator use. All topics except 'Sets, counting and probability' were covered by the twenty-one tasks and calculator use supported conjecture and practical applications.

The views of Kemp, Kissane, and Bradley (1996) on assessment with graphics calculators in an undergraduate course are also highly relevant to our inquiry. Kemp et al. discuss the design of questions so that graphics calculators are (a) expected to be used, (b) expected to be used by some students and not others, or (c) not expected to be used. Strategies for expected use are the inclusion of explicit instructions to use the calculators, and/or usage of numbers and functions etc. for which by-hand processing would be very inefficient. One purpose for such questions is testing the calculator skills required by a course. If it is intended that some students and not others will use the graphics calculator, then by-hand processing and processing on the technology must be clear alternatives, and the choice will depend on students' competence and beliefs. Strategies for disabling the use of the calculator are to use simple numbers and expressions so that calculator use is inefficient; to include parameters in numerical expressions; to require students to show algebraic working and to not simplify their answers, to base questions on graphs and tables of values of functions that have not been defined in terms of formulae; and ask for the representation of information in real-world situations, explanation of reasoning, and justification of answers.

Monaghan (2000) also reports on assessment strategies and discusses effects on examinations overall, in relation to the use of CAS calculators in the A level examinations in the UK. Many of his observations are relevant to assessment with graphics calculators. He identifies strategies for setting questions which test understanding. These include to pose questions where computation is easy and

and interpretation of results is required, to give results and ask students to ‘show that’, or ask them to ‘deduce from a result that’. He suggests to ask for methods to be specified, examine several approaches within a question (e.g., algebraic and graphical methods), split questions into steps to test understanding of process, and he advocates setting more questions in context. He suggests that effects of these strategies are that questions will focus more on basic principles than is presently common, but acknowledges that questions may become more wordy, and the difficulty of examinations may increase.

In summary, the available literature on graphics calculator use in non-calculus mathematics subjects defines the scope of the use, provides examples of questions for assessment that are made possible by the technology, and provides strategies for constructing questions. In this paper we document changes in the Applicable Mathematics TEE questions since the introduction of graphics calculators.

Research Method

Initially we coded all questions in the Applicable Mathematics TEE (Secondary Education Authority, 1992a-1996a; Curriculum Council, 1997b-2003b) according to the syllabus topics that they addressed. We individually worked the questions for each topic, intentionally documenting the decisions we made and alternative methods, then negotiated agreement on our work. We identified trends in the questions, and searched examination reports (Secondary Education Authority, 1992b-1996b; Curriculum Council, 1997c-2003c) for relevant comments and the mean percentage scores, and contacted two teachers about available programs and checked local web sites (Ref 1, Ref2). Finally we sought critique on this paper by an examiner who has held office since before the calculators were introduced. She responded: “It certainly makes interesting reading and I think accurately reflects the feelings of the examiners over time”. She pointed out that: “the examiners purposely make some questions easy and others hard and the same topics are therefore intentionally not examined at the same level each year”. Our analysis should be read with this in mind. She also responded to two claims in the paper, which we indicate in the text.

Results

The most noticeable effects of the availability of graphics calculators on questions are as follows. In the topic ‘Systems of linear equations and matrices’ there is wider use of parameters, and the format of questions that involve solution of a system using inverse matrices has changed (see below). In the topic ‘Graphs and solutions of equations’, more complex functions are used, exponential regressions are expected (consequent to them being introduced to the syllabus), and changes in linear programming questions that first appeared in 1996 have persisted (see below). Questions on ‘Descriptive statistics’ have required interpretation of calculator screen displays that have been imported into the questions, and more comparison of exponential and linear models. More complex probability density functions have been introduced in the topic ‘Random variables and their distributions’ and probabilities can be obtained from the calculator instead of mathematical tables. There has been little impact on questions on ‘Sets, counting and probability’. The findings are consistent with our study of school-based assessment (Forster et al., 2003).

Linear programming

Each examination in the period 1992-2003 has included a single linear programming question. Characteristics of the questions and mean percentage marks are summarised in Table 1. Marks are not available for 1992 and 1993. The year 2000 question is provided below to illustrate the characteristics. The relevant syllabus objective for all years was: “model a variety of optimisation problems involving two variables as linear programs, and solve graphically" (Curriculum Council, 2002a, p. 49).

Table 1: Format, requirements, and mean % scores for TEE questions on linear programming, 1992-2003

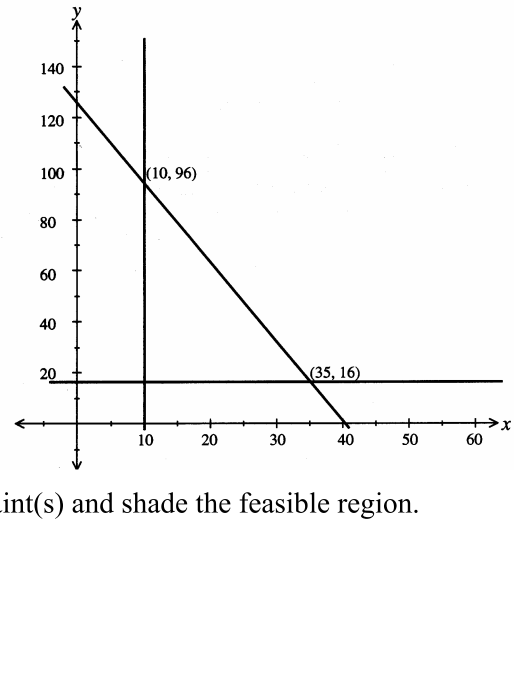
	92	93	94	95	96	97	98	99	00	01	02	03
Format												
Numerical information in text	√	√	√	√	√	√		√	√	√	√	√
Numerical information in table	√											
Letters for variables specified					√	√		√	√	√	√	√
Constraint(s) specified algebraically					√	√		√				
Graph provided					√	√	√	√	√	√	√	√
Corner-point solutions provided							√	√	√		√	√
Requirements												
[a] No. constraints to formulate	4	3	3	3	2	[b] 2		[b] 4	4	4	4	6
No. constraints to graph	4	3	3	3		1			1	1	2	
No. corner-points to determine	3	2	4	4	4	4		2	2	5	4	
Formulate objective function	√	√	√	√	√	√	√	√	√	√	√	√
Optimise objective function	√	√	√	√	√	√	√	√	√	√	√	√
Sensitivity analysis	2	2	1	1	1	1	1	1	1	1	1	1
Other interpretation		1						1	1	1	1	1
Mean percentage score	-	-	79	60	86	67	37	72	65	72	51	36

[a] expressions for upper and lower bounds, e.g., $1 \leq x \leq 2$, were counted as a single inequality

[b] formulation was necessary even for algebraic expressions that were given, so that numerical, algebraic and graphical information could be linked

2000 question (Curriculum Council, 2000b, pp. 28-29)

A factory has a contract to manufacture exclusive merino wool knitwear. A trial suggests that jackets will take 3.2 hours each and vests will take one hour each to machine knit. The jackets will each take 48 minutes to assemble, label check and package, while the vests will each take 30 minutes. The factory has 128 hours of available machine hours for knitting a week and 40 hours a week for assembling labelling, checking and packaging. At least 10 jackets and 16 vests must be produced each week to fulfil a regular order. Each jacket can be sold at a profit of \$100 and each vest can be sold at a profit of \$40. Let x be the number of jackets and y be the number of vests produced in a week. Some of the above constraints are drawn on the following graph. [the graph has been reduced to about half-size]



(a) Draw the remaining constraint(s) and shade the feasible region.

(b) Assuming all jackets and vests that are manufactured are sold, state how many of each should be manufactured in a week for a maximum profit. Justify your answer and state the maximum profit.

A new design jacket will cost less to produce but can be sold for the same amount as the previous jacket, thus profits will increase. The factory still wants to maintain its regular orders but switch to production of a new design.

(c) What is the increase in the profit per jacket that will give the most flexibility in the number of vests and jackets manufactured, whilst still maintaining orders and maximising profits (assuming all are sold)? State all possible combinations of numbers of vests and jackets that could be manufactured (and sold) for the maximum profit.

The questions on linear programming from 1992 to 1995 (see Table 1) all comprised the following steps: determination of the decision variables, formulation of the constraints and objective, construction of the feasible region, determination of the corner-point feasible solutions, evaluation of the objective function at these points to locate the optimum, and sensitivity analysis for the coefficients of the objective function.

The provision of graphs was a major change to the questions in 1996 (see Table 1). The change coincided with the introduction of 'write-on' papers and persisted after 1998 when graphics calculators were introduced. Reasons for continuing to provide graphs (which were confirmed in the personal communication from the examiner) are that some brands of calculator have inbuilt capabilities for graphing inequalities and others do not, and graphing inequalities is not a minimum requirement of calculators for the TEE. Hence, making the graph available 'levels the playing field'. Usually the graphs included some inequalities only and students were asked to add the missing ones (1996-1997, 2000-2002, see Table 1). The write-on papers made this practical, as the graphs in the question did not have to be copied onto separate paper. The missing inequalities always had to be formulated first. So both the ability to formulate a constraint and to graph the constraint boundary were assessed.

Another change is that corner-point solutions were provided after 1997, via the graphs or in a table of values. In the years 1999-2002 only some points were given and others had to be calculated solving simultaneous equations. Coordinates could be read from the graph and checked using substitution. The need to check, use algebra, or use the calculator was greater if the given graphs had no grid (see the 2000 question). Thus, the capacity to obtain corner point solutions one way or another was assessed via the determination of some points only, and repetitive processing to obtain all points was avoided.

A further simplification was the complete specification of the decision variables, and again this was associated with the provision of graphs (see Table 1). The specification has involved labelling coordinate axes with letters and describing the letters in the given information (see the 2000 question). Prior to the provision of the graph, letters were not provided and the variables were mentioned only in the part questions. Thus, an effect of providing the graph is that much less effort is needed in deciding the decision variables. We suggest that more attention needs to be given to assessing performance on this non-trivial aspect of linear programming.

In 1998 no numerical information was given in the text of the question. In our view the low mean percentage score on the question (see Table 1) was partly due to this aspect because it mediated against coherence in working the solution. We found that only superficial interpretation of the given graph was possible and that producing answers relied on mechanical application of procedures. The examiners (Curriculum Council, 1998c) reported that the main problems were that students did not obtain all of the optimal solutions and did not know how to go about the sensitivity analysis.

In fact, examiners often report difficulty with sensitivity analysis, when it involves the determination of new coefficients for the objective function so that the optimal solution changes (which was the case in 1998 and in part (c) of the question in 2000). The analysis calls for abstract thinking, and it seems that the impact of calculator availability on success with these part questions has been minimal. Students do not seem to find the other sensitivity calculations as difficult (determining optimal solutions for changed resources and for cost changes that are given). The impact of the calculator on success with these also seems minimal.

The 2003 question also attracted a low mean percentage score (Table 1). In order to solve the optimisation problem, it was necessary to consider two linear programming problems with the same objective function and two common constraints. The remaining constraints were different. The feasible regions for both problems were disjoint and were given on the same graph without making clear that two distinct linear programming problems were to be considered. In order to proceed through the question the constraints had to be matched to the graph so as to identify the two problems. We suggest that the very low mean score is largely explained by these aspects of the question.

Two requirements of the linear programming questions that have not changed are the formulation of objective functions and optimisation of the functions (see part (b) of the 2000 question). The introduction of graphics calculators has made little impact on the ways these questions are asked and solved. Last, we note the increased call for interpretation of results (see Table 1). This has always involved interpretation of results in terms of the situation. See part (c) in the 2000 question: sensitivity analysis was required, then further exploration of the feasible region to decide the possible combinations.

In summary, graphics calculator availability explains the continued provision of graphs in the linear programming questions. Formulation and graphing are still assessed through requirements to add to the graph; and selected corner point solutions only are required, which reduces repetitive processing. There has been little impact on cost function and sensitivity analysis but assessing ability to identify decision variables has been neglected. In the 1998 and 2003 questions, when the calculators were available, key information was not provided and key steps in linear programming were not required in the solutions, and mean percentage scores were low.

Systems of equations

Each of the Applicable Mathematics examinations for 1992-2003 has included at least two questions on systems of linear equations. They have required formulation only (in 1993, 1998, 2000 and 2003), formulation and solution (1992 and 1994), or solution only because the systems were already set up. We focus on the expected methods of solution, which are using the inverse of the coefficient matrix, and Gaussian elimination. Questions that require the use of the inverse matrix are treated first and their characteristics are summarised in Table 2. There were no questions of this type in 1992-1993. The table needs to be read in conjunction with the relevant syllabus objectives. From 1992 to 1997 these were: "calculate the inverse of a 2×2 matrix and recognise a singular matrix" and "given an $n \times n$ matrix ($n \leq 3$) and its inverse, verify that their product is the identity matrix" (Curriculum Council, 1997, p. 38). The second objective changed in 1998, when the graphics calculators were introduced and became: "given an $n \times n$ matrix, find the inverse and use it to solve the corresponding system on n linear equations in n unknowns” (Curriculum Council, 2002a, p. 48). Calculator use was expected for coefficient matrices of size greater than 2×2. The 1997 and 2000 questions are provided below the table to illustrate the common characteristics.

Table 2. Format and mean % scores for TEE questions on systems of linear equations with invertible coefficient matrices 1994-2003

	94		95	96	97	98	99	00	01	02	03
Formulation required											
Method prescribed	√	√	√	√	√	√	√	√	√	√	
System in equation form	√	√	√	√	√	√					
Coefficient matrix supplied		√	√	√	√					√	√
Matrix equation supplied								√	√	√	√
Inverse or a multiple of it supplied		√	√	√	√		√				
No. of variables	2 …	3	3	3	3	4	3	4	4	4	5
Variables specified	√	√	√	√	√	√	√	√	√	√	√
Request to explain method						√		√			
Request to write down the inverse						√		√	√	√	
Request to interpret the result								√	√	√	√
Mean percentage score	69		63	77	71	69	70	91	86	85	68

[a] A matrix for premultiplication was supplied that was not a scalar multiple of the inverse matrix (see below)

1997 question (Curriculum Council, 1997b, p. 10)

(a) Calculate AB if $A = \begin{bmatrix} 3 & 2 & 1 \\ 2 & 1 & 1 \\ 2 & 3 & 1 \end{bmatrix}$ and $B = \begin{bmatrix} 2 & -1 & -1 \\ 0 & -1 & 1 \\ -4 & 5 & 1 \end{bmatrix}$.

(b) Showing all working, use a method involving matrix multiplication to solve the following system of equations:

$$\begin{aligned} 2x - y - z &= 22 \\ y - z &= 18 \\ -4x + 5y + z &= -20 \end{aligned}$$

2000 question (Curriculum Council, 2000b, p. 5)

Four consecutive customers visiting an outback caravan shop bought bread (loaves), milk (litres), newspaper(s) and petrol (litres). The quantity of each item bought by each customer and their total cost (dollars) are represented by the matrix system of equations below, where *b, m, n* and *p* are the cost of one loaf of bread, one litre of milk, one newspaper and one litre of petrol respectively.

$$\begin{bmatrix} 2 & 1 & 1 & 15 \\ 3 & 3 & 2 & 10 \\ 1 & 1 & 1 & 0 \\ 2 & 1 & 1 & 20 \end{bmatrix} \begin{bmatrix} b \\ m \\ n \\ p \end{bmatrix} = \begin{bmatrix} 21.45 \\ 21.50 \\ 3.90 \\ 26.70 \end{bmatrix}$$

(a) Indicate clearly how a method using inverse matrices can be used to find the costs of the individual items.

(b) Write down the appropriate inverse matrix.

(c) Find the cost of each individual item.

In accordance with the syllabus objectives prior to the inclusion of graphics calculators, if there were more than two variables and matrix size was greater than 2×2, the coefficient matrix and its inverse or a closely related matrix were supplied (see Table 2). Then, the usual way to examine knowledge of the inverse method was to ask for computation of the product, which was equal to a diagonal matrix (1995) or a scalar matrix (1994, 1996, 1997), and the relationships could be used to solve the system. See the 1997 question, where $AB=2I$, so that $B^{-1} = A/2$. With the calculators, students have been asked to calculate the inverse from the coefficient matrix (see the 2000 question above), or vice versa (in 1999), and write down the inverse matrix and the solution to the system.

Points about the two styles of question are, first, if the pattern of the early questions had continued after 1998, use of the graphics calculator would have relieved students of tedious multiplication and have allowed them to focus on the relationship between the matrices and its relation to the solution of the system of equations. As well, understanding of the relationship would have been assessed through asking students to use the relationship to solve the system. Second, with the new style of question, writing down the inverse matrix is a trivial task that is not needed for coherence in the solution. The requirement (with marks allocated to it) partly explains the high mean percentage marks on the questions in the years 2000-2002 (see Table 2). One reason for the 'writing down' requirement is to ensure that solution via the inverse is used (Examiners' report, Curriculum Council, 2000c). However, even if students are prompted to calculate the inverse there is no way of checking that they solve the system with it. The ease with which results can be produced on the calculator using either multiplication by the inverse matrix or Gaussian elimination suggests that there is no need to specify a method and in fact this was taken up in 2003.

The lower mean marks in 1998 and 1999 (cf 2000-2002) are attributable to the new question format and the call for explanation in 1998, and the twist that the inverse and not the coefficient matrix was given in 1999 (Curriculum Council, 1998c, 1999b). Other aspects of the questions are that, starting in 2000, interpretation of the results has been required. Simple interpretation was called for in 2000-2002, and complex interpretation explains the low mean score in 2003 (see Table 2).

Another aspect of the questions is an increase in the number of variables since the introduction of the calculators (see Table 2), and this can be linked to the syllabus objective to find the inverse for any $n \times n$ matrix (see above). More variables result in more time spent on repetitive processing (whether by hand or on the calculator), which is problematic unless the context of the question demands them. The contexts in all the questions that have been asked could have been described with two or three variables. One other outcome is that students tended to perform well on the explanation in 2000 (Curriculum Council, 2000c).

In the examinations, more general aspects of solutions of systems of equations are dealt with in the context of examining competence with the use of the elementary row operations, according to the Gaussian elimination method. The syllabus objectives for this have not changed. They are that students should: "solve systems of linear equations in two and three variables by elimination" and "examine the coefficient matrix of a system of linear equations, and the relationship between row operations on the coefficient matrix and rearrangements of the equations" (Curriculum Council, 2002a, p. 48). The characteristics of the questions on Gaussian elimination are summarised in Table 3, and the question from 2002 is provided for illustration.

Table 3. Format, requirements, and mean % scores for TEE questions on solution theory for systems of linear equations 1992-2003

	92	93	94	95	96	97	98	99	00	01	02	03
Format												
Tabular Information			√									
System of equations supplied	√			√	√	√	√	√	√	√	√	√
Augmented matrix supplied						√						
Parameters	√			√	√		√	√	√	√	√	
Requirements												
Set up augmented matrix		√	√	√	√		√	√	√	√	√	√
Reduce to row echelon form	√	√	√	√	√		√	√	√	√	√	√
Interpretation of row echelon form	√	√	√	√	√		√	√	√	√	√	√
Mean percentage score	-	-	71	[a] 69	59	48	37	44	78	47	37	[a] 68

[a] The solution of the system of equations was a small part of a larger question

2002 question (Curriculum Council 2002b, p. 18)

The following system of linear equations

$$x + 2y - 3z = 4$$
$$4x - y + 2z = 5$$
$$6x + 3y + az = 10$$

can be represented in matrix form by $AX = B$, where A is a singular matrix. If a belongs to the set of real numbers, how many solutions exist for the system? Justify your answer clearly.

The most common pattern in the questions across all years (see Table 3) is that a system of linear equations with 3 equations and 3 unknowns is given, and parameters are used for one or more of the coefficients and/or for the constants. Students were to set up the augmented matrix, reduce it to row echelon form, then solve for the parameters or determine how many values they could take, according to conditions that were specified (see the 2002 question). Examiners' reports indicate that errors with reduction are common when parameters are included, and that students have difficulty with the interpretation of the meaning of the parameter values (e.g., Curriculum Council, 2002c). Particularly low mean percentage scores (see Table 3) are explained by high numbers of parameters (1999), parameters that were squared (1998, 2001), and complexity due to the conditions (2002). Consequences of the various uses of parameters, apart from increasing the level of difficulty, are variation within the common question style, which serves the examination purpose, and they preclude the use of the calculators.

The inclusion of parameters forces students to carry out the elementary row operations by hand. If the issue is to test the ability to apply the solution theory for linear systems, the use of a system of equations with numerical coefficients would be adequate if in-built facilities are the only ones allowed, for the steps in the reduction are either not displayed or must be provided by the user. However, customised programs are available that carry out step-by-step reduction for 3 × 3 systems stating the sequence of operations, and the number of solutions (see Ref1 and Ref2). The availability of these programs has virtually forced the use of parameters to assess if students have mastered the solution theory for systems of size 3 × 3. We note that different questions appeared in 1994, 1997 and 2003. The 1994 question had no parameters and involved finding the number of solutions. In 1997, students were asked to detect errors in a worked solution and this resulted in relatively a low mean score (see Table 3). In 2003, a non-square matrix was used and students had difficulty with this aspect (Curriculum Council, 2003b).

Conclusion

One issue highlighted by our inquiry is that with the introduction of new technologies new stereotype questions emerge over time. On one hand, the new forms may allow assessment of key aspects of a solution process as is the case with the provision of the graph in linear programming questions. On the other hand, they may introduce unnecessary tedium or requirements that are trivial. In addition, some processes may be neglected in new types of question. An example is the definition of decision variables in linear programming. However, the similar but slightly different process of defining variables for systems of equations is examined--in the formulation only questions (a point that was noted in personal feedback from the examiner).

Retention of old types of question with requirements for particular methods or for explanation of the method is another option when technologies are allowed in examinations (Kemp et al., 1996; Monaghan, 2000). We showed that there is scope for these approaches in questions on solving systems of equations using inverse matrices. Interpretation of results may also be emphasised and this was evidenced in the questions on linear programming and matrix inversion. In addition, higher-level interpretation has been required in Gaussian elimination questions since the advent of the calculators. Reasons are barring calculator-use and having variety in the questions.

References

Bradley, J. (1999). Discernable trends ineffective graphics calculator use in examinations. *Australian Senior Mathematics Journal, 13*(1), 55-63.

Curriculum Council (1997a, 2002a). *Syllabus Manual Year 11 and Year 12, Mathematics*. Perth, Western Australia: Curriculum Council. http://www.curriculum.wa.edu.au

Curriculum Council (1997b-2003b). *Tertiary Entrance Examination, Applicable Mathematics*. Perth, Western Australia: Curriculum Council.

Curriculum Council (1997c-2003c). *Tertiary Entrance Examination Report, Applicable Mathematics*. Perth, Western Australia: Curriculum Council.

Forster P. A., Mueller, U., Haimes, D., & Malone, J. (2003). Impact on school assessment where use of graphics calculators is mandatory in a related public examination. *International Journal of Mathematical Education in Science and Technology, 34*(3), 343-359.

Kemp, M., Kissane, B., & Bradley, J. (1996). Graphics calculator use in examinations: Accident or design. *Australian Senior Mathematics Journal, 10*(1), 36-50.

Kendal, M., & Stacey, K. (2001). The impact of teacher privileging on learning differentiation with technology. *International Journal of Computers for Mathematical Learning, 6*(2), 143-165.

Monaghan, J. (2000). Some issues surrounding the use of algebraic calculators in traditional examinations. *International Journal of Mathematical Education in Science and Technology*, *31*(3), 381-392.

Secondary Education Authority (1992a-1996a). *Tertiary Entrance Examination, Applicable Mathematics*. Perth, Western Australia: Secondary Education Authority.

Secondary Education Authority (1992b-1996b). *Tertiary Entrance Examination Report, Applicable Mathematics*. Perth, Western Australia: Secondary Education Authority.

Ref1 www.charliewatson.com/casio/casprog.html

Ref2 www.hphomeview.com