POLICY CHANGE, GRAPHING CALCULATORS AND 'HIGH STAKES EXAMINATIONS: A VIEW ACROSS THREE EXAMINATION SYSTEMS

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This paper focuses on policy changes brought about by the implementation of the graphics calculator into high stakes end of high school mathematics examinations. The paper uses a comparative approach to consider how two examination authorities, located in Denmark, Australia along with an International examination authority went about establishing policies for the introduction of the graphics calculator and later how these authorities had to adapt these policies to meet changing needs. Similarities and differences in the implementation process are also described.

INTRODUCTION

In the early 1990's the graphing calculator (hereafter GC) first began to appear in mathematics classrooms in the USA, Australia and many European countries. These calculators provided the rapid production of graphs and incorporated all the functionality of the scientific calculators that were already being used in high school mathematics. The "early adopters" in many countries felt that these calculators would allow students to develop a better conceptual understanding of mathematics by supporting an investigative approach to mathematics (Dunham & Dick, 1994; Penglase & Arnold, 1996). The introduction of the GC soon led to calls for their use in examinations (Harvey, 1992). These calls immediately provided challenges for those responsible for setting examinations (hereafter known as Examining Authorities, EA) as the GC had the capacity to complete many of the traditional pencil and paper test items with the push of a button. The EA's needed to develop policies that took account of a wide range of competing requirements in mathematics examinations, such as equity, the style of questioning, the rules concerning what was an acceptable written solution, whether questions should be GC active or should be excluded all together. In conjunction with, a recognition of the marked increase in the repertoire of techniques and skills a student was required to assimilate (Drijvers & Doorman, 1996).

This paper, reports on part of a larger comparative study by (Brown, 2005), and has its focus on the changes in policy within three "national" EA's as they went about implementing the introduction of the GC into their system wide 'high stakes' end of secondary school mathematics examinations. The three authorities are the Danish Ministry of Education (DME), Denmark, the International Baccalaureate Organization (IBO) and the Victorian Curriculum and Assessment Authority (VCAA), Victoria, Australia are described in the following section. Followed by a description of the research project and the policy initiatives enacted by the EA's. The paper concludes with a discussion of these policy initiatives.

EXAMINATION AUTHORITIES (EA)

The Danish Ministry of Education (DME)

The Danish Gymnasium programme is a three-year course leading to the Upper Secondary Leaving Examination. At the time of the study there were two courses of study from which the students choose one: the language line and the mathematics line, the focus of this study. For the mathematics line all students must complete at least B-level mathematics a (2 year course) whilst the majority choose A-level mathematics, either as a three-year course, or as a one-year course after B-level.

International Baccalaureate Organization (IBO)

The International Baccalaureate Diploma Programme caters for over 1800 schools in more than 124 countries (IBO, 2006) and is an internationally recognized pre-university qualification. The International Baccalaureate therefore provides an interesting contrast to a national system, its cross cultural mix of students, teachers and examiners as well as its three different languages provides a contrasting set of values to those, which appear in a national system. Like the other examination boards described in this paper all students must select at least one mathematics course from the 3 programmes offered.

Victorian Curriculum and Assessment Authority (VCAA)

The Victorian Curriculum and Assessment Authority (VCAA, formerly the Victorian Board of Studies (VBOS)) administer the Victorian Certificate of Education (VCE). The aim of the VCE programme is to provide students with a qualification, giving them access to universities. The course of study is a two-year course leading to the Victorian Certificate of Education. There are three courses of study in mathematics from which the students may choose one or two.

Differences

There are a number of structural differences between the three examination boards. The government of Denmark, through the Minister of Education is directly responsible for the management and administration of examinations and curricula development. Whereas in Victoria, the VCAA is a statuary authority, which reports directly to the Minister of Education, but retains some independence from the government. Whilst the IBO is a non-profit educational foundation governed by a Council of Foundation located in Switzerland. Thus whilst in the cases of the VCAA and the DME there is governmental monitoring of the educational administration, in the case of the IBO it is managed by elected representatives from each of the regions.

METHODOLOGY

A descriptive multiple case study (Yin, 1994) was used for the larger study as it met the requirement of being able to take account of a wide range of variables within the contemporary context of the study of policy implementation. The criteria established relating to the selection of EA's for the study were;

- Similar curricula and a final high school 'high stakes' mathematics examinations prior to university entrance
- Two stage process for the implementation of the GC into the mathematics examinations, that is allowed use followed by required use
- Examination authorities at similar stages of the implementation i.e. the GC adopted at similar times

The relevant EA documents relating to the policies, curriculum and examinations that accompanied the introduction of the GC into the EA's 'high stakes' examinations formed the data for this study and included

- Curriculum documents for each of the 3 EA's (DME, 1993, 1999b; IBO, 1987, 1997b, 1998; VBOS, 1996c, 1999b)
- Examinations from each EA (DME, 2007; IBO, 2007; VCAA, 2007a; VCAA 2007b)
- Other policy statements issued in respect to the use of technology and conduct of examinations (DME, 1996, 1997a, 1997b, 1998, 1999a, 1999c; IBO, 1992, 1995, 1997a, 1997c, 1999; VBOS, 1995, 1996a, 1996b, 1996d, 1997, 1998, 1999a, 1999c)
- Interviews with the question writers for each of the EA's regarding the setting of examinations in a GC assumed environment with a follow up survey of the questions writers.

This study was partly historical as it considered the changes that had been put in place prior to the introduction of the GC and then considered how these policies were modified to take account of the skills to be assessed with pencil and paper versus those where students could use technology along with newer models of the GC. As a consequence the study was not affected by policy changes during the data collection phase, in contrast to Paechter's (2000) study, where the researcher had to incorporate ongoing changes of policy.

RESULTS: COMMONALITIES

This paper will describe the policy decisions that took place as a response to or aligned with the introduction of the GC into 'high stakes' examinations. These are described in the following section.

Mathematics content changes and graphing calculator specifications

In all cases there was minimal changes to the curriculum and in each case these changes were not directly attributable to the introduction of the GC.
Each authority established its own requirements concerning the types of GC allowed in the examinations. These decisions were driven by a number of factors including the functionality of the GC and the availability of various brands and models (especially

relevant for the IBO). There were two approaches to such decisions, either an open approach with restrictions on maximum capabilities (e.g. GC could not have symbolic manipulation capabilities (DME, 1999b; IBO, 1999a; VBOS, 2000)) or to provide minimum specifications, e.g. GC must have the following capabilities (or functionality)

- decimal logarithms, values of x^y and $x^{1/y}$, value of π, trigonometric and inverse trigonometric functions, natural logarithms, values of e^x

(IBO, 1999b)

Statements in curriculum guides on use of technology in Mathematics

In the case of the VCAA there were outcome statements that specifically indicated the expectation regarding the use of technology (including the GC) which stated that

> Outcome 3
> On completion of each unit the student should be able to select and appropriately use technology to develop mathematical ideas, produce results and carry out analysis in situations requiring problem-solving, modelling or investigative techniques or approaches. (VBOS, 1999b, pp. 161- 162)

Further descriptions of the how this Outcome Statement could be achieved were also provided (VBOS, 1999c). However, for the IBO there were minimal statements on the use of the GC within the curricula and assessment materials. The DME Mathematics Faculty consultant stated that

> … we do not require students to do very much with a graphic calculator simply because the way that the law is written is that they should just have a graphic calculator. We don't have requirements that they should have a TI83 (Texas Instruments GC) or whatever. So all we can build on is they are able to draw graphs and so on (DME3, 2001).

This lack of specification was of concern to the faculty consultant and indicates the difficulties of introducing technology without setting standards for that technology.

Use in all examinations

In the cases of the IBO and the VCAA, the GC was required in all mathematics examinations, however for the DME only one of the examinations required the GC, the other was technology free. The reason for this is not directly related to the introduction of the GC but instead is a result of government legislation. The Danish government legislated that at least one of the examinations should be technology free (DME, 1997), as a result of publicly expressed concerns regarding the skill level of students in mathematics at the end of gymnasium level (Christoffersen & Svaneborg, 1996).

Implicit or explicit statements on the use of the GC in an examination question.

Examiners responsible for writing questions struggled with the setting of questions in a GC assumed environment, and it soon became evident that some questions could be solved with the push of a button whilst others were unaffected by the GC. So examiners, and EA's, resorted to ways to ensure that students either did not waste their time trying to solve a problem algebraically when a GC solution was more appropriate or the skill being tested was to be done without the GC. Each of the EA's in this study developed statements to restrict or encourage the use of the GC these are summarized in the table 2.

EA	Graphics Calculator Excluded	Graphic Calculator Active
DME	Solve by calculation; Calculate Find equation of tangent Use definite integral	Use your graphics calculator
IBO	Find exact	Use your graphics calculator; Write down approximated coordinates; Find to an accuracy of six significant figures
VCAA	Use Calculus; Find exact	Find to an accuracy of three significant figures

Table 2: Statements used on examinations to indicate the use (or non use) of the GC in a particular question.

Interestingly the restriction of the use of the GC excluded questions ranged from 0% for the IBO to 47% for one mathematics subject in the VCAA (Brown, 2005). Perhaps indicating that for some examiners they were still focused on the assessment of skills that had been automated by the GC.

Guidelines for acceptable graphics calculator based solutions.

Each of the boards provided rules for what constituted an acceptable GC based solution, which are summarised in the following table, Table 3.

EA	Working and Marking instructions
DME **(DME, 1999a)**	A mark would be awarded for a correct answer and possibly incorrect one (but close), but without an explanation of the method used and information included, such as a sketch of the graph (including indicating the window dimensions), it would not be possible to obtain full marks.
IBO **(IBO, 1999b)**	Where candidates are asked to show, prove or justify their answer, then correct mathematical reasoning must be used. A reference to a calculator operation such as "I used the Solve command to find that …" would be insufficient. When candidates are answering questions they will be expected to demonstrate their mathematical set up of the solution before using the GDC. That is, candidates need to demonstrate their thought processes in the development of their solutions. Correct mathematical terminology must be used to gain method marks If candidates are required to find the solution to a problem which can be solved using the inbuilt functions of the GC, other than those normally found on a scientific calculator (eg sin, cos, tan), they are required to show all the steps in the solution
VCAA **(VBOS, 2000a)**	Where a numerical answer to a question, or part of a question, is required, this may be obtained using any of analytical, numeric or algebraic approaches as appropriate unless instructed otherwise.

Table 3: Instructions to students on an expected response to an examination question

It can be seen that the EA's have slightly different policies regarding the instructions given for a GC based solution. In the case of the DME and the IBO these instructions specify that working must be shown, whereas for the VCAA the instructions indicate that when a GC is used in a question then any solution can be found by any method.

The DME first published their instructions after the completion of the standard-level mathematics written examinations in 1999. These instructions were intended to indicate the mark allocation for differing GC based solutions ranging from zero marks to full marks for a complete solution with all working including a description the GC window. Whereas, the IBO has specified that working must be shown and the use of correct mathematical notation is required. In contrast the VCAA has focused on describing when and when not to use a GC solution. It is apparent therefore, that the examining boards have different expectations on what a GC based solution should look like.

DISCUSSION

This study considered the policy changes that coincided with the introduction of the GC, as well as those implemented prior to the first GC required examinations. The initial policy announcements by the EA's indicated that the GC would be required in examinations from the year 2000. These announcements were followed by curricula and assessment documents, which recognised the new policy but provided little evidence of change in the content of the curriculum or the structure of the examinations.

However, as the first examinations requiring the GC approached further policy initiatives were introduced. These included

- Setting minimum specifications of the functionality of the GC
- Indicating when, and when not, to use the GC in examination questions
- Describing what constitutes an appropriate GC based solution
- Use of no GC examinations

The realisation of the need for these changes can be seen as a consequence of two issues surrounding the GC. Firstly, the capability of the technology and secondly, the need for fairness for all students sitting the examinations.

In terms of the GC's functionality prior to the introduction of the GC many mathematics questions could only be completed with the use of a standard algorithm, which the question writers wanted assess a students' ability to use. However, the GC opened up a multiplicity of methods to the student (Arnold & Aus, 1997a, 1997b; Ruthven, 1996), thereby making difficult for question writers to assess a particular skill. The introduction of technology has led to a debate on mathematics skills (see Gardiner, 1995; Ralston, 1999; Waits & Demana, 1998; Wong, 2003; Wu, 1998, for a wider discussion), which the question writers inadvertently become part of when writing examination questions. The EA's, in their attempt to side step the mathematics skills issue, endeavoured to follow a middle path and tried to balance these competing solution methods by using key words that restricted the solution method to a particular problem or left it open to the student to choose. Within the parliament in Denmark a debate had ensued on the skill level of students leaving the Gymnasium and as a consequence a "technology free" examination paper was introduced (DME, 1997a). The implementation of this examination paper, however, was not directly attributable to the introduction of the GC but part of the ongoing mathematics skills debate in that country. The use of such a paper did not limit the use of questions in the technology allowed paper where the wording indicated when the GC was not to be used.

Many of the problems that question writers faced from a technological standpoint can be explained by (Kaput, 1998) who stated that "The computational medium alters the growth of mathematical content, changes which content is important and for whom, changes the means by which it can be known, taught or learned …" (p. 1) As stated earlier for all EA's, the GC had been introduced into a virtually unchanged mathematics curriculum, furthermore, only limited changes to examination procedures were deemed necessary to accommodate the GC. The minimal changes to the curriculum and assessment models were admirable, and undoubtedly intended to help teachers feel less threatened by the introduction of the GC. However, it left question writers with the challenge of 'retrofitting' a new technology to an older curriculum, especially given recognition on the part of the question writers, and others (Kieran & Drijvers, 2006), of the difference between GC and pencil and paper techniques.

High stakes examinations are intended for the purposes of 'certification, selection and motivation' (Peterson, 1987) and as a consequence these examinations must ensure that they are valid assessments of the content of the curriculum as well as ensuring that the assessments are fair to all. Where fairness of assessment implies that "the test results neither overestimate nor underestimate the knowledge and skills of members of a particular group … Fairness also implies that the test measures the same construct across groups." (Gollub, Bertenthal, Labov, & Curtis, 2002, p.143). Question writers are therefore bound to ensure that there is a 'level playing field' for all students sitting the examinations as well as ensuring that the examination is an assessment of the curriculum. To ensure fairness the EA, whilst assuming that all students have covered the content of the curriculum, are required to take account of the differences in the types of technology available as well as capability of such technologies. Thus the EA's have felt obliged to set minimum requirements for the technology as well as excluding some types of GC from examinations. The difficulties associated with not establishing minimum requirements are clearly indicated by the faculty consultant in Denmark who stated, "it is up to the teachers to decide how much they want to use the facilities of the GC other than the most basic ones."(DME3, 2001), thus presenting a dilemma for question writers, how much do they assume that the teachers and students know about the functionality of the GC.

CONCLUSION

Each of the three examination boards saw the need to develop additional policies that accompanied the introduction of the GC. In particular these policies were required to take account of differing functionalities within available technologies, endeavouring to come to terms with "what mathematics skills should be tested", (an unresolved debate (Forster, Flynn, Frid, & Sparrow, 2004). And combined with minimal change to the curricula content and the structure of the examinations then question writers resorted to the use of particular instructions so that they could assess students knowledge of a particular skill or concept.

It is apparent therefore that Examination Authorities considering introducing hand held or possibly computer based technologies into their high stakes examination systems need to take the following into account

- how they will take account of the range of capabilities of the allowed technologies,
- how they will ensure that the examination assess the skills as laid down in the curriculum,
- whether they need to rewrite their mathematics curricula,
- whether the current examination structure is appropriate.

In conclusion EA's will need to recognise that technologies continue to develop and they will need to establish policy structures that allow changes to take place as the availability and affordability of advanced technologies places them in the hands of students.

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